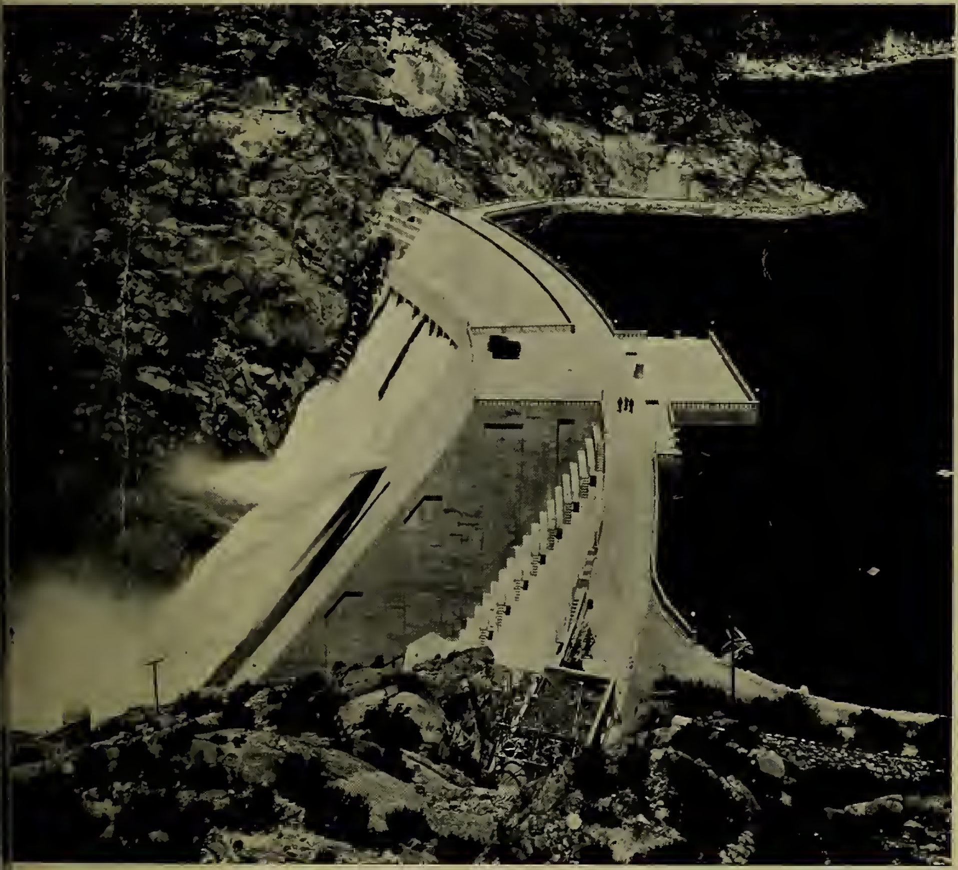
THE HETCH HETCHY WATER SUPPLY AND POWER PROJECT

OF SAN FRANCISCO



O'SHAUGHNESSY DAM

M. M. O'SHAUGHNESSY, Mem. Am. Soc. C. E.
City Engineer, San Francisco

November, 1931.

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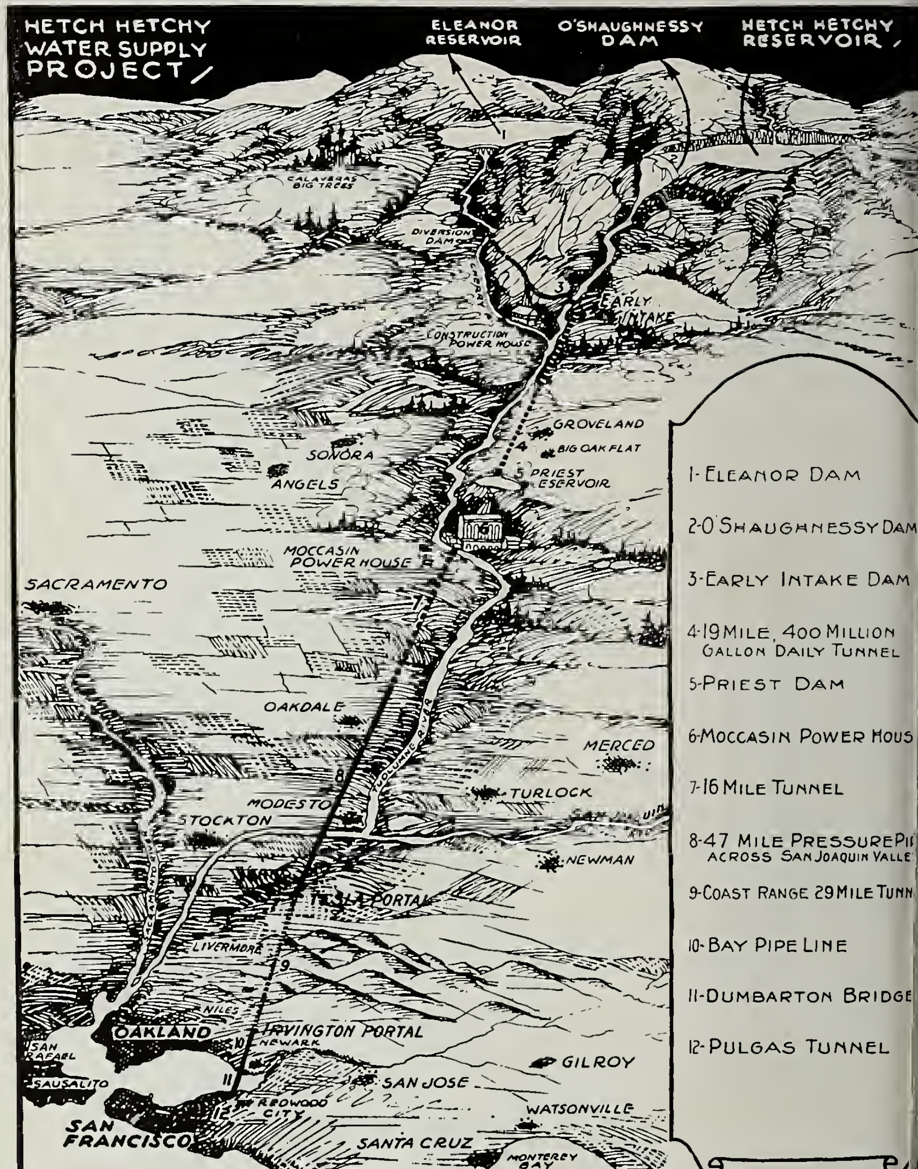

GENERAL SKETCH OF PROJECT

FOREWORD

The government of San Francisco is to be conducted in the future along new lines to be established by the Charter which goes into effect on January 8, 1932. A Public Utilities Commission is to assume control of the City's utilities. Among these the Hetch Hetchy Water Supply and Power Project and the Municipal Railway stand forth as the greatest completed assets of the City.

In a year of political activity such as the present, much discussion of the water project arises, especially from persons ignorant of facts, and from sensational newspapers anxious to provoke controversy. This booklet has been prepared to present the facts about this great work, which steadily is approaching completion.

The project is sound in every respect. Its general plan was conceived along the bold lines of modern engineering. Its construction is an example of good, substantial work, designed to endure. Upon its completion, every citizen should rejoice that his City is further strengthened to maintain its position of supremacy on the Western Coast.

In the design and construction of this work I have been aided by an able staff of assistants, some of whom have passed to the great beyond, for whose work I have the highest appreciation.

I particularly commend the work of L. T. McAfee, Chief Assistant Engineer, and his predecessor, Nelson A. Eckart; L. W. Stocker, Chief Designing Engineer; P. J. Ost, Chief Electrical Engineer; and R. P. McIntosh, Hydraulic Engineer, since deceased. I am indebted to L. B. Cheminant, Assistant Engineer, for preparation of this booklet.

M. M. O'SHAUGHNESSY,
City Engineer.

November 7, 1931.

ABBREVIATIONS

Cubic foot or feet	cu. ft.
Cubic yard or yards	cu. yd.
Circular mils	c. m.
Elevation	elev.
Foot or feet	ft.
Gallon or gallons	gal.
Horsepower	h. p.
Hour or hours	hr.
Inch or inches	in.
Kilovolt-amperes	kv-a
Kilowatt or kilowatts	kw
Mile or miles	mi
Million gallon or gallons	m. g
Million gallons daily	m. g. d
Pound or pounds	lb
Revolutions per minute	r. p. m
Second foot or feet	sec. ft
Square foot or feet	sq. ft
Square mile or miles	sq. mi

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HETCH HETCHY WATER SUPPLY AND POWER PROJECT, 1931

THE SYSTEM DEFINED

Hetch Hetchy Water Supply, named for the valley which forms its principal impounding reservoir, is the future water source of San Francisco. When developed to its ultimate capacity it will furnish more than 400 m. g. d., or sufficient water for four million people and by taking due advantage of drops in elevation, will produce more than 250,000 h. p. of hydroelectric energy.

The waters coming from the melting snows and glaciers of the Sierra Nevada are now impounded in two reservoirs, Hetch Hetchy on the main Tuolumne River and Lake Eleanor on one of its tributaries. From these reservoirs a gravity aqueduct 138 mi. in length leads to the peninsular reservoirs in San Mateo County. This aqueduct, closed throughout, consists of 67 mi. of tunnel and 71 mi. of pipe which may be considered as used primarily for water, and a portion of it secondarily for power.

At present the reservoirs have been developed to furnish sufficient water for the needs of about two million persons. Two power plants are in operation, producing over 100,000 h. p. of energy. The aqueduct is approaching completion, which is expected in 1933, but the adoption of the temporary expedient of pumping water through a pipe line over the Coast Range Mountains, will actually bring Hetch Hetchy water to the city by the middle of 1932.

The project has been designed throughout with the utmost care after meticulous study and its construction is being carried on in line with the most modern engineering methods to insure first-class results in every respect.

WATER SUPPLY BY PRIVATE COMPANIES

The Padres in exploring the coast northward from Monterey, selected a sheltered valley with a stream of water in which to found the Mission St. Francis de Assisi, now commonly called Mission Dolores, in 1776.

As time went on the newer settlers obtained water from springs and creeks which, with the addition of water imported in barges from Sausalito, sufficed for many years.

In 1851 an attempt to utilize the waters of Mountain Lake and Lobos Creek in San Francisco was made by Mountain Lake Water Company. In 1857 the water of Lobos Creek was actually developed by San Francisco Water Works which built a flume with tunnel through Fort Point, thence to Black Point at the foot of Van Ness Avenue, with a pumping station which forced the water up into two reservoirs on Hyde Street, which are still in in service. From these reservoirs pipe lines were extended throughout the settled portion of the city. This water was introduced on September 16, 1858. After considerable litigation between the two companies, the Mountain Lake Company failed in 1862 and went out of business.

Meanwhile another company, called Spring Valley Water Works, was organized under a charter from the Legislature. In 1858 this company took up a spring near Mason and Washington Streets and laid a few pipes. With the acquisition of substantial funds the company in 1862 brought in a supply from Pilarcitos Creek in San Mateo County to Laguna Honda reservoir by means of a redwood flume 32 mi. in length. Previous to this time it had acquired the Islais and Salinas Water Company which was using water from Islais Creek, brought into a reservoir at Sixteenth Street and Potrero Avenue, a portion of which reservoir still exists as a playfield in the school grounds.

A spirited fight which then ensued between the two water companies resulted in 1865 in a "consolidation" by which Spring Valley Water Works absorbed the other company. From then on this company extended its works in San Mateo County until 1886 when with the continuing growth of the city and additional demand for water, it became necessary to develop sources in Niles Canyon in Alameda County. At the present time the system of the company, under normal rainfall conditions, is capable of developing from 60 to 65 m. g. d. As will be noted later, the voters on March 1, 1928, authorized a bond issue for $41,000,000 to finance the purchase of this company's property. Operation was taken over by the City on March 3, 1930, and vested in the San Francisco Water Department of the Board of Public Works.

The City is underlain by extensive sand and gravel deposits which are pierced by numerous wells. Many industrial establishments in the City obtain large amounts of water from these wells.

The total amount so developed is difficult to ascertain, but probably reaches 8 m. g. d. In addition to this the City, as an emergency measure, recently has developed a series of wells along Forty-fourth Avenue in the Sunset District near the Ocean Beach, which yield 6 m. g. d. of sweet water.

ATTEMPTS AT MUNICIPAL OWNERSHIP

The history of operation of the private water company was one of constant conflict with the people and the government of the City. As early as 1867 friction developed and far-seeing citizens then began to realize that the most satisfactory final solution of the problem was municipal ownership of the water system. Investigations of water supply with a view to this purpose were made under the Board of Supervisors from 1871 to 1874. In this latter year an engineer named Scowden recommended that the City acquire Niles Canyon and Calaveras Valley on Alameda Creek, the main tributary of which is Arroyo Honda draining the north slopes of Mt. Hamilton. While the City was negotiating for this purchase, the water company acquired the lands and water rights in question. This purchase appears to have squelched the movement for municipal ownership as but little was done from then until adoption of the new charter in 1900.

In May, 1882, J. P. Dart, a civil engineer of Sonora, Tuolumne County, prepared a map showing the route proposed by Tuolumne and San Francisco Water Company to bring water from the Tuolumne River above Jacksonville to San Francisco. Various other mountain sources were suggested in 1889 and 1894. The United States Geological Survey Annual Report of 1899-1900 contained a report on Hetch Hetchy and suggested it as a source which could furnish San Francisco with 250 gallons daily per capita for a population of one million.

A provision of the Charter of 1900 "that its public utilities shall be gradually acquired and ultimately owned by the City and County," forced the Supervisors to take steps toward the acquisition of a municipal water supply. During the administration of Mayor Prelan in 1900 and 1901, the City Engineer made an exhaustive investigation of fourteen sources:

Spring Valley Water Works	San Joaquin River
Lake Tahoe	Clear Lake and Cache Creek
Yuba River	Stanislaus River
Feather River	Mokelumne River
American River	Tuolumne River
Sacramento River	Bay Shore Gravels
Eel River	Bay Cities Water Company

This investigation established the superiority of the Tuolumne River system, later called the Hetch Hetchy system, principally for the following reasons:

1. Purity of the water.
2. Largest amount of water available.
3. Largest and best reservoir sites.
4. Freedom from conflicting legal claims.
5. Power possibilities.

Steps were taken immediately toward acquisition of rights. Appropriations of the water of Tuolumne River and of Eleanor Creek were made under the California laws. The complication in the selection of Tuolumne River lay in the fact that both Lake Eleanor and Hetch Hetchy lie within Yosemite National Park, which is under the jurisdiction of the United States Department of the Interior.

Applications for permission to build the necessary dams within the Park, filed October 16, 1901, were denied June 20, 1903, by Secretary of the Interior Hitchcock and the denial was reaffirmed on September 22, 1903, on the ground of lack of authority of the Secretary to make such a grant. An attempt was then made to secure legislative action in Congress, but the bill was shelved by a hostile Lands Committee of the House of Representatives. In February, 1905, an appeal to the President brought forth an explanation of the denial by the Secretary wherein he claimed that Congressional action would be necessary. An opinion to the contrary was given by the Attorney General, but this was not made known until 1906.

The great fire caused an interruption to consideration of the application, but on July 24, 1907, Secretary Garfield reopened proceedings with hearings in San Francisco and on May 11, 1908, he approved the original application as filed in 1901, under what is known as the Garfield Permit.

The Garfield Permit, which was revocable under certain conditions, granted to the City rights of way for conduits, dams and reservoirs in Yosemite National Park, subject to certain important restrictions, some of which are as follows: The City was required to develop Lake Eleanor and Cherry reservoirs to full capacity before beginning work at Hetch Hetchy; the City must recognize and protect the prior rights of the Turlock and Modesto Irrigation Districts to a flow of 2,350 cu. ft. of water per second from the Tuolumne River; the City was to permit the districts to construct storage works above Lake Eleanor and Hetch Hetchy; the City was required to sell to these districts at cost, any surplus electric power not actually required for pumping

the water or for actual municipal purposes of the City (which purposes should not include sale to private persons nor to corporations). It must be noted that this permit would have prohibited San Francisco from commercial sale of its own power.

On November 12, 1908, the citizens voted a bond issue of $600,000 with which to purchase lands and water rights necessary for the development. On January 14, 1910, another bond issue in the amount of $45,000,000 was authorized with which to construct a complete water system. On February 25, 1910, the new Secretary of the Interior Ballinger cited the City to show cause why the Hetch Hetchy part of the permit should not be revoked, thus leaving the city with only Lake Eleanor and Cherry Valley. As it would not have been good economics to build the long aqueduct to utilize the relatively small amount of water which could be developed from these two sources and as the offcials of the City did not think that it was advisable to be subject to the whims of successive Secretaries of the Interior, they decided to ask Congress for an outright grant of the desired privileges.

In this year the City Attorney engaged the services of John R. Freeman, noted hydraulic engineer of Providence, R. I., now one of the engineers of the New York Board of Water Supply, to prepare material with which to present the City's claims before Congress. Mr. Freeman redesigned the entire project in the light of modern engineering to what is known as the "Freeman Plan" of development which, with slight modifications, has been substantially followed in the present construction. This plan provides for the delivery of 400 m. g. d. instead of the 60 m. g. d. under previous plans. It provides for extensive development of hydro-electric energy for commercial sale and revises the plan so as to bring the water to San Francisco by an all-gravity route instead of by pumping. The unfortunate part of his plan was that he estimated construction costs on a basis of common labor at $2.50 per ten-hour day when the Charter required a minimum of $3.00 per day.

On May 18, 1910, President Taft had appointed a Board of Army Engineers, consisting of Colonel John Biddle, Lieutenant-Colonel Harry Taylor, and Major Spencer Cosby to review all engineering matters in question. This board of engineers examined exhaustively all alternative sources of supply which had been suggested as available for San Francisco's use and in a report made to Secretary of the Interior Fisher, under date of February 19, 1913, recommended the use of the Hetch Hetchy supply as being not only the most available but the cheapest and most economical for the City's use and affording the greatest possibilities for hydro-electric development. An extended and heated battle was waged in the halls of Congress where the City's application was opposed by nature lovers and the representatives of irrigation, power and water interests, but the Hetch Hetchy grant, known as the Raker Act, was passed by both houses and signed by President Wilson on December 19, 1913.

The Raker Act granted to San Francisco the rights of way and the use of public lands in the Yosemite National Park, the Stanislaus National Forest, and elsewhere, for the purpose of constructing, maintaining and operating reservoirs, dams, conduits, and other structures necessary or incident to the development and use of water and power.

Some of the stipulations inserted in the Act provide as follows:

The City is empowered to enforce certain sanitary regulations within the watershed tributary to the reservoirs and aqueduct.

The City is required to recognize the prior right of Turlock and Modesto Irrigation Districts to receive from the natural daily flow of Tuolumne River, measured at La Grange, such water as can be beneficially used by them, up to 2,350 cu. ft. per second.

The City is required to develop electric power for municipal and commercial use.

The City is required to construct certain roads and trails and donate them to the United States.

The City must pay an annual rental graduated up to a maximum amount of $30,000.

The City shall undertake and vigorously prosecute to completion at Hetch Hetchy a dam at least 200 ft. high.

The City . . . "shall not divert beyond the limits of the San Joaquin Valley any more of the waters of the Tuolumne watershed than, together with the waters which it now has or may hereafter acquire, shall be necessary for its beneficial use for domestic and other municipal purposes."

The Act expressly avoids interference with the laws of California relating to the control or appropriation of water, which is of extreme importance because San Francisco holds its water rights under the California law and not under the Raker Act.

The provisions of the Act are extended to the "City and County of San Francisco and such other municipalities or water district or water districts as may, with the consent of the City and County of San Francisco or in accordance with the laws of the State of California, hereinafter participate in or succeed to the beneficial rights and privileges granted by this Act."

In the spring of 1914 San Francisco ratified the conditions of the Raker Act and planned a construction program. In starting any business enterprise, it is of the greatest importance that the income which is to support the enterprise should commence as early as possible, so that the interest and other fixed charges on the investment shall not be a burden on the investors any longer than absolutely necessary. In the Hetch Hetchy project it required only the construction of the main storage dam and the upper 20 mi. of the aqueduct to reach the ¼-mi. power drop at Moccasin Creek, so the decision was made to concentrate all energy and financial resources on the works above Moccasin power plant for the threefold purpose of developing and protecting the water rights under the state law, of producing an income from power sales that could be applied to reduce the burden of interest and bond redemption on the taxpayers, and to comply with the stipulations of the Raker Act.

Construction began in July, 1914, shortly after the beginning of the World War. Prices of all commodities rose sharply and upon the entry of the United States into the war, great difficulty was experienced in securing men, money and materials for the prosecution of the work. During this

period the City carried on work with a force of from 400 to 500 men, with due care always not to interfere with the selective draft or the nation's need for materials and equipment. Progress was necessarily not as rapid as otherwise would have been the case. All energy was bent toward construction of the power system which went into operation August 14, 1925, delivering power which has been sold at the rate of approximately $2,000,000 per year.

Since 1925 the work has been prosecuted on a schedule calling for completion in 1932, which was determined as the earliest time that the water could be transmitted to San Francisco in compliance with the Raker Act.

WATERSHEDS AND STORAGE RESERVOIRS

The principal storage reservoir, Hetch Hetchy, was made by building O'Shaughnessy Dam, the construction of which will be described later. Tributary to this reservoir there are 459 sq. mi. of rugged granite mountains of which the highest, Mt. Lyell, attains an elevation of 13,090 ft. About 92 per cent of this area is above 6,000 ft. elevation and is uninhabitable except for about three months in summer.

This entire section lies within Yosemite National Park and on it there is not one permanent habitation. All of this land belongs either to the United States Government or to the City and County of San Francisco. There will, therefore, be no possibility of pollution of the watershed by human activities such as camping, mining, cattle raising, or farming. The entire area is composed of granitic rocks largely without soil or vegetation so that it forms an ideal watershed. Mr. Allen Hazen, noted sanitary engineer, stated in the Freeman report to the Army Board "it would be difficult to conceive of a more perfect gathering ground or one better adapted to produce water of greater purity. The water will be almost ideally safe."

The present plans contemplate no treatment of the water by filtration, aeration, chlorination or any other dosage. On the basis of a hardness of less than 20 for Hetch Hetchy water and 100 for the water then in use in San Francisco, Mr. Hazen estimated that the substitution of 60 m. g. d. of the mountain water would represent a saving of soap and water softeners in the City amounting to $175,000 annually. Chemical analysis of a sample of water taken from Hetch Hetchy reservoir at a point about one mile easterly from the dam, shows 14.8 parts per million of total solids and a hardness of 2.58 parts per million as calcium carbonate.

The quantity of water available from Tuolumne River is ample for the combined requirements of San Francisco and the Turlock and Modesto Districts. The total runoff of the Tuolumne River measured at La Grange averages about two million acre ft. annually. The requirements of San Francisco with the Hetch Hetchy project developed to its maximum will consume about one-quarter of this flow.

The watershed area directly tributary to Lake Eleanor comprises 79 sq. mi. and is entirely within the boundaries of Yosemite National Park. Additional watershed tributary to the reservoir by diversion through a flood canal from Cherry Creek, totals 114 sq. mi. This lies within Stanislaus National Forest. A further area of 32 sq. mi. drains into Eleanor Creek, Cherry River, and Tuolumne River between the main storage reservoirs and the diversion dams which turn the water into the aqueduct.

Hetch Hetchy Reservoir with O'Shaughnessy Dam built to its present height of 344.5 ft., stores 67 billion gal. or 206,000 acre ft. The ultimate storage with the dam built to its full height of 420 ft. will be 113 billion gal. or 348,000 acre ft. The present reservoir is 7½ mi. long and has a maximum width of ¾ of a mile. The flow of Tuolumne River is sufficient during the one month of June of any normal year to fill the present reservoir twice.

For water supply purposes the present stage of development of the two reservoirs is ample for the requirements of two million people. For power generation, the development is sufficient in normal years but not during dry seasons.

The Pacific Gas and Electric Company, which acts as the City's agent for distributing power, is obligated to take the full amount of energy that can be produced at the Moccasin plant. Consequently, to obtain the maximum income, the water is drawn from the reservoirs at full capacity of the aqueduct tunnels, which under certain conditions exceeds 400 m. g. d.

A draft of this magnitude will deplete Hetch Hetchy reservoir in the early winter, unless heavy early rains occur. Obviously, it then becomes necessary to operate the power house on a diminished scale with stream flow during part of the winter months. This condition might be modified by con-

HETCH HETCHY RESERVOIR

struction of the addition to O'Shaughnessy Dam, and it is quite certain that this work will be advisable for power development much earlier than for water development.

Lake Eleanor, the second main storage reservoir, lies about 5 mi. northwesterly from Hetch Hetchy. The level of the original natural lake was raised 35 ft. by construction of Lake Eleanor Dam, which will be described later. The present Lake Eleanor reservoir has capacity of 9 billion gal., or 28,000 acre ft., which may be increased by future construction of a rock fill dam to 71 billion gal., or 218,000 acre ft.

Statistics relative to these two reservoirs and to other reservoirs possible on the Tuolumne River watershed, will be found later on in this booklet.

CONSTRUCTION FEATURES

PREPARATORY WORK

Before proceeding with the construction of the essential parts of the aqueduct it was necessary to complete several auxiliaries. The sites of both Hetch Hetchy and Lake Eleanor reservoirs lie within the National Park. Prior to the construction of dams at these points these regions were accessible only by trail. Large amounts of construction machinery and material were required for work in constructing these dams and for the tunnel work, so it was decided to built a standard gauge railroad from the Sierra Railway, 26 mi. east of Oakdale, through the mountains for transportation of men and materials.

A careful study was made of the question of power for construction use, as a result of which it was decided to build a construction power plant which would furnish adequate electric energy for all the construction operations.

The City owned valuable timber lands within Yosemite National Park and close to its borders, consequently it was deemed advisable to build a sawmill to utilize this timber for construction. Many miles of roads were built, telephone and power lines installed, and water supplies developed for the various construction camps.

Hetch Hetchy Railroad:

The Hetch Hetchy Railroad was a major piece of construction. Location surveys were made by C. R. Rankin from a connection with Sierra Railway of California at a point 26 mi. from Oakdale to the rim of Hetch Hetchy Valley, a distance of 68 mi. The minimum grade was 4 per cent and the sharpest curve 30 degrees, or 190 ft. radius. The railroad was located so as to give most convenient and cheapest transportation to the various construction camps along the aqueduct route. The highest point on the railroad, Poopenaut Pass, six mi. from Hetch Hetchy, is at elev. 5,064. Grading began in 1916 and was completed in October, 1917. Total amount of excavation exceeded 1,000,000 cu. yd. The railroad was operated from July, 1918, to February, 1925, as a common carrier with freight rate base 12½

cents per ton mi. for carload lots and passenger fare base 7½ cents per mi. The cost of construction of the railroad was approximately $3,000,000. During the peak of transportation six City locomotives with one rented locomotive were in constant service, day and night. The operation of the railroad resulted in much earlier completion of the structures in the mountains than would have been possible with other means of transportation.

Sawmills:

Sawmill machinery was purchased in August, 1915, and a sawmill erected in Yosemite National Park at Canyon Ranch, 4½ mi. from Hetch Hetchy. After 6,000,000 board ft. of lumber had been sawn at this location the timber supply was exhausted and the sawmill was moved in 1919 to Mather, which is 9 mi. from Hetch Hetchy. At this latter point operation was continued until 1924 when, having served the needs of construction to that time, its operation was discontinued. The sawmill was not dismantled, as it may prove of value for construction at a later period. About 21,000,000 board ft. of lumber was cut. This was shipped from the mill on the City's own cars over its own railroad to the various camps to be used for concrete forms, camp buildings, flumes, tunnel timbering, and miscellaneous structures. High grade lumber such as sugar pine, not required in the City's work, was traded to privately operated mills for a greater quantity of lumber suitable for construction use.

EARLY INTAKE FROM HETCH HETCHY RAILROAD

SNOWPLOW ON HETCH HETCHY RAILROAD

CITY'S SAWMILL AT MATHER STATION

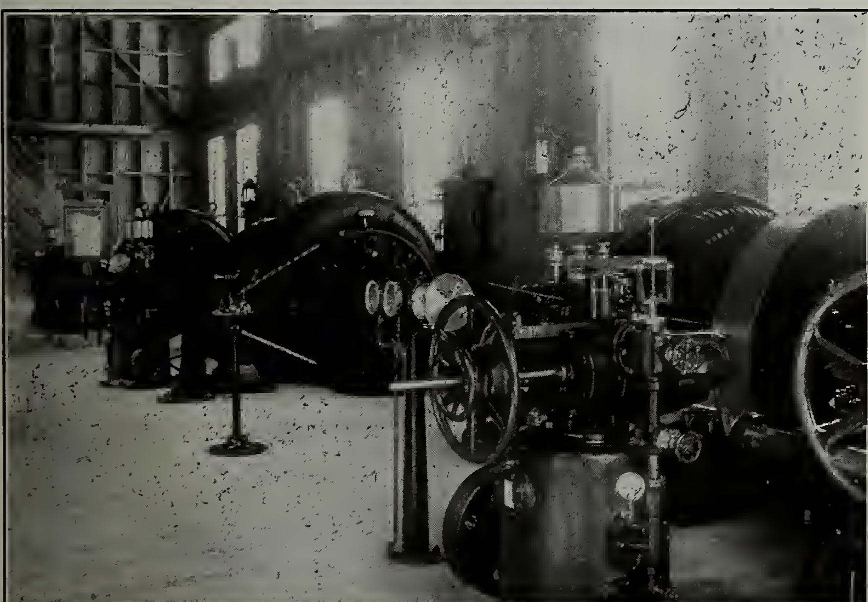
HETCH HETCHY RAILROAD BRIDGE OVER TUOLUMNE RIVER

Construction Power Plant:

Power for construction requirements was obtained from a 4,500 h. p. plant constructed on the Tuolumne River for this purpose near its junction with Cherry River. This plant utilizes the water stored in Lake Eleanor to drive 3 Pelton-Francis turbines operating under a maximum head of 345 ft. and direct connected to three 2,300 volt 1000 kv-a generators. The transmission line, operated at 22,000 volts, extends 11 mi. easterly to O'Shaughnessy Dam and 22 mi. westerly to Moccasin Creek. Such power as is generated in excess of the requirements of the work is sold and has netted the City well over $500,000. This power house has been in operation since May, 1918.

LAKE ELEANOR DAM

To provide water for continuous operation of the construction power plant during the low water season, Lake Eleanor Dam was built. Its location is on Eleanor Creek about 1 mi. downstream from the outlet of Lake Eleanor, a typical glacial lake. The level of this lake was raised 35 ft. by construction of a buttressed arch dam 1,260 ft. long and 70 ft. high with crest elev. 4,661 ft. The central portion of the dam consists of 20 arches, each with a span



EARLY INTAKE CONSTRUCTION POWER PLANT TURBINES AND GENERATORS

LAKE ELEANOR BUTTRESSED ARCH DAM

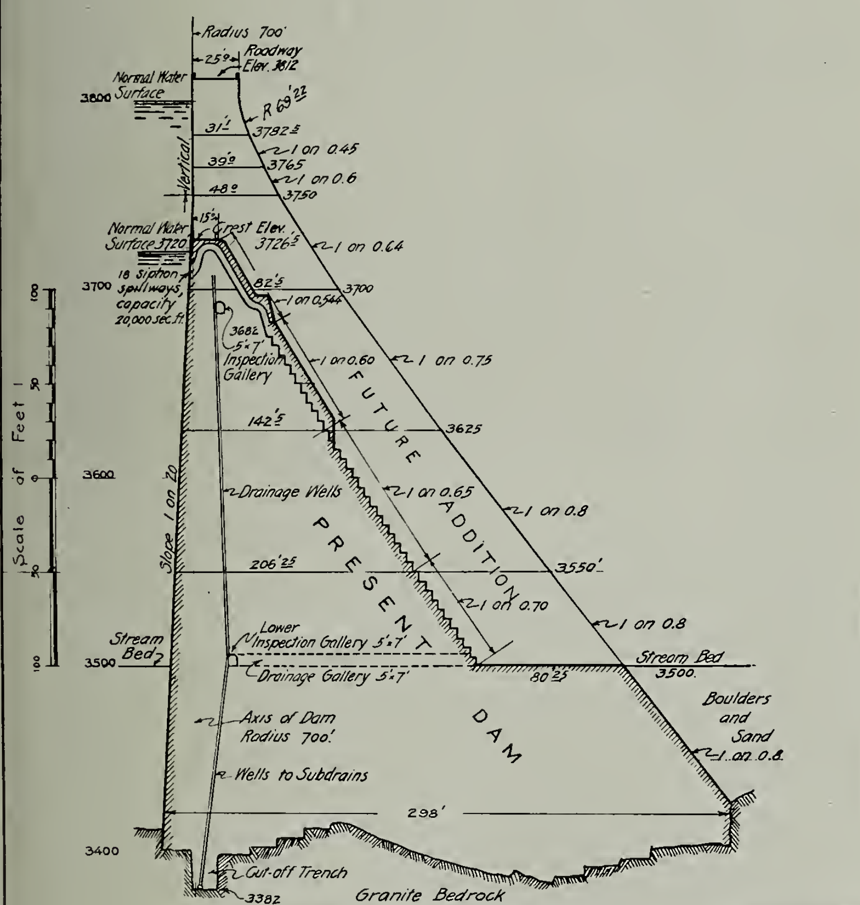
of 40 ft. The arches are on an incline of 50 degrees to the horizontal and are supported by buttresses. The two ends of the dam are built as gravity section. The southerly end contains an ample spillway with provision for flash-boards to raise the water elev. 4 ft. to the top of the dam. The stored water is released through four 24-in. gates. The dam contains 11,640 cu. yd. of concrete very heavily reinforced and cost approximately $300,000. All the work was done by day labor, employed under direct supervision of the City Engineer, in the remarkably short time of 18 months. This dam may in future be used as the upstream toe of a rock fill dam 235 ft. in height, which is particularly adapted to the conditions at this site.

O'SHAUGHNESSY DAM

Prior to appointment of M. M. O'Shaughnessy as City Engineer on September 1, 1912, it had been thought that 30 ft. would be ample depth of foundation for the dam across Tuolumne River. Under his direction wash borings and diamond drill borings were made, which disclosed the fact that the damsite was at the terminal moraine of an ancient glacier and that the river channel between the cliffs was occupied largely by boulders with thin intervening beds of sand to depths of 90 ft. or more below river level. During construction of the dam it became necessary to excavate to 118 ft. below

river level to the deepest point of the cut-off wall. Bedrock was encountered at 61 ft. depth at the downstream toe and 101 ft. at the upstream toe.

Certain preliminary work was undertaken by small day labor crews and on August 1, 1919, a contract for construction of the dam was awarded to



HETCH HETCHY WATER SUPPLY OF THE CITY AND COUNTY OF SAN FRANCISCO, CALIFORNIA.

O'SHAUGHNESSY DAM
AT
HETCH HETCHY VALLEY

CROSS SECTIONS SHOWING PRESENT AND FUTURE DAMS.

DEPARTMENT OF PUBLIC WORKS. APPROVED M.M. O'Shaughnessy CITY ENGINEER

BY LSC TRACED LSC CHECKED

SCALE As shown DATE June 12, 1925.

A 287.

Utah Construction Company. The dam is of the arched gravity type with radius of 700 ft. Crest elev. is 3,726.5 ft. It is built of cyclopean concrete, which consists of plain concrete with about 8 per cent of granite "plums" or blocks of stone ranging in size from 1 cu. ft. to 5 or 6 cu. yd. embedded in the mass.

All modern features for safety are provided. There are five vertical contraction joints sealed by strips of sheet copper, which divide the structure into six blocks. Precast porous concrete drainage wells were built to intercept any possible leakage and lead it through galleries out through the back of the dam. On each contraction joint there is an inspection well with ladderway. These inspection wells lead to inspection galleries which pierce the interior of the dam.

To comply with the requirements of the Raker Act, and for other reasons, the dam was built initially to a height of only 226.5 ft. above stream bed. Plans for future development, however, require a dam 312 ft. above stream bed, or of 430 ft. total height. In building the present dam the foundation was built of ample dimensions to support the necessary 85½ ft. extra height. The central portion of the dam, which now contains the outlet valves and conduits, was built to full section of the future dam or approximately 80 ft. thicker than the other portions.

The length of crest of the present dam, 605 ft., will become 900 ft. in in future. The foundation has a maximum thickness of 298 ft. and contains 77,346 cu. yd. below stream bed. Total concrete, inclusive of parapet wall, is 398,516 cu. yd.

The present wasteway consists of 18 siphon spillways each 4 x 10 ft. at the throat, with capacity of 20,000 cu. ft. per second, which discharge floods over the downstream face of the dam. There are 12 outlet conduits through which water from the reservoir may be passed through the dam. Six of the conduits are regulated by sluice gates 47 x 90 in. and by balanced needle valves 5 ft. in diameter. The other six have 33 x 42-in. sluice gates and 3-ft. diameter balanced needle valves. The valves and appurtenances comprise over 2,000,000 lb. of metal of high grade design and cost nearly $700,000. Three of the discharge conduits are in the diversion tunnel through which the flow of Tuolumne River was carried past the foundation excavation during construction of the dam. This tunnel, approximately 1,000 ft. long, was 23 x 25 ft. and was driven through solid granite. At the time of construction of the discharge conduits the diversion tunnel was plugged with concrete.

The greater part of the concrete consists of 1:3:6 mix with no rock larger than will pass a 2½-in. mesh screen. Plum stones were not permitted to lie closer than 2 ft. to the face of the dam or the rock in the abutments, or closer than 1 ft. to forms, construction joints, etc., or closer than 6 in. to one another. Mass concrete placed next to the upper face and to part of the downstream face in the outlet section and other places, is a 1:2½:5 mix with rock to pass a 2-in. mesh screen. Reinforced concrete such as in the spillways is a 1:2:4 mix with rock to pass a 1-in. mesh screen. Dense

concrete blocks around the inspection wells are precast with 1:2:4 mix and rock to pass a 1-in. mesh screen. Porous concrete blocks around drainage wells are 1:1:8 mix.

Concrete operations were carried on day and night, summer and winter. During the very cold weather a heating plant was used to prevent the concrete from freezing. The greatest amount of concrete poured in one month was 41,178 cu. yd. Maximum amount placed in one day was 2,000 cu. yd. In general the concrete was poured in 5-ft. layers, keeping the downstream face always from 5 to 15 ft. higher than the upstream face. Precast concrete screen racks, circular in plan, were built in the reservoir face to prevent debris, such as trees, from entering the outlet conduits and interfering with operation of the valves. The dam is surmounted by a concrete parapet rail, precast in sections, of most pleasing design, which gives it a very beautiful appearance.

The cement was hauled from the factory in bulk and handled by appropriate machinery from box cars to mixers. All batches were weighed. Sand was obtained from a pit in Hetch Hetchy Valley about 3 mi. upstream from the damsite. The rock was obtained from talus slopes on the north side of the valley and consisted entirely of granite.

The cost of the entire work in and around the reservoir, including construction of the dam, clearing reservoir site, and other accessories, is slightly in excess of $8,000,000.

Before the dam was completed the entire floor of Hetch Hetchy Valley was cleared of timber so as to protect the impounded water from contamination due to decay of submerged timber. Upon completion, the dam was officially named O'Shaughnessy Dam in honor of its builder.

FUTURE DEVELOPMENT BETWEEN RESERVOIRS AND EARLY INTAKE

At present the water flows from the reservoirs to Early Intake largely in the natural stream channels. The water from Hetch Hetchy reservoir flows down Tuolumne River from O'Shaughnessy Dam, which is 167 mi. from San Francisco, a distance of 12 mi. to Early Intake. The water from Lake Eleanor flows about 8 mi. in Eleanor Creek and Cherry River to a diversion dam, which turns it into lower Cherry aqueduct. This aqueduct, which has a capacity of 200 second ft., is approximately 4 mi. long and consists of 1.2 mi. of tunnel, 1 mi. of concrete lined canal, and 1.8 mi. of flume and steel pipe. A portion of the Lake Eleanor water is used to run the construction power plant and the remainder continues beyond this plant to unite with the Hetch Hetchy water above the Early Intake diversion dam. The construction power plant is run at peak load during periods when there is an excess flow in Cherry River. At other times it is more effective to divert the water into the main aqueduct tunnel so that it may be used with the Hetch Hetchy water at Moccasin power plant.

Future development of Lake Eleanor dam, as hereinbefore outlined, will be followed by construction of a concrete aqueduct about 8 mi. long from Lake Eleanor to the rim of Tuolumne River canyon near North Mountain,

which is above Early Intake. Here penstock pipes with a drop of over 2,000 ft. will carry the water to North Mountain power house where 40,000 h. p. will be generated and the Lake Eleanor water discharged into Tuolumne River to enter the aqueduct at Early Intake as it now does. Future development of power from Hetch Hetchy reservoir alone is planned by construction of a tunnel about 11 mi. long, leading from O'Shaughnessy Dam along the southerly canyon wall of Tuolumne River, from which penstock lines with a drop of about 1,200 ft. will conduct the water to Early Intake power house, of 60,000 h. p. capacity, on the bank of the river at Early Intake. There are no satisfactory sites for forebay reservoirs for these two power houses, so they will be run at constant load and all regulation will be done at Moccasin power house, as will be described later.

EARLY INTAKE DIVERSION WORKS

At Early Intake, 155 mi. from San Francisco, the combined waters from the Eleanor and Hetch Hetchy watersheds are turned out of the river channel to enter the aqueduct leading to San Francisco. The diversion dam which accomplishes this purpose consists of a thin concrete arch 262 ft. long, with a concrete spillway 130 ft. long, containing a total of 16,564 cu. yd. of 1:2:4 concrete. On the left bank is the aqueduct intake tower in which the flow is regulated by nine sluice gates each 4 ft. by 5 ft., set in two tiers in an arch of 16 ft. radius abutting against the solid granite canyon wall. The dam has an upstream radius of 100 ft. Thickness at the crest at elev.

EARLY INTAKE DIVERSION DAM

2,356 ft. is 6 ft., at the base 16 ft. Height above river bed is 55 ft. and the base extends 26 ft. down to solid granite. On the south, or left bank, the arch abuts the granite canyon wall. On the north is a built-up, concrete abutment block containing 3,611 cu. yd.

From this block the spillway extends northerly, divided by piers into 5 sections, each 23 ft. long, in which automatic radial gates have been installed, which function to maintain the water surface at elev. 2,346 ft., or 5 ft. above the lip of the spillway. Tunnel invert at inlet is at elev. 2,326 ft. A siphon arrangement automatically lowers these spillway gates a depth of 5 ft. to pass excess floods and allows them to rise automatically after the flood subsides. In constructing the arch section of the dam two vertical openings with keyways 18 in. wide were left at the points of approximate zero bending moment until the dam had taken final set. Then in the extreme cold weather these keyways were filled with concrete.

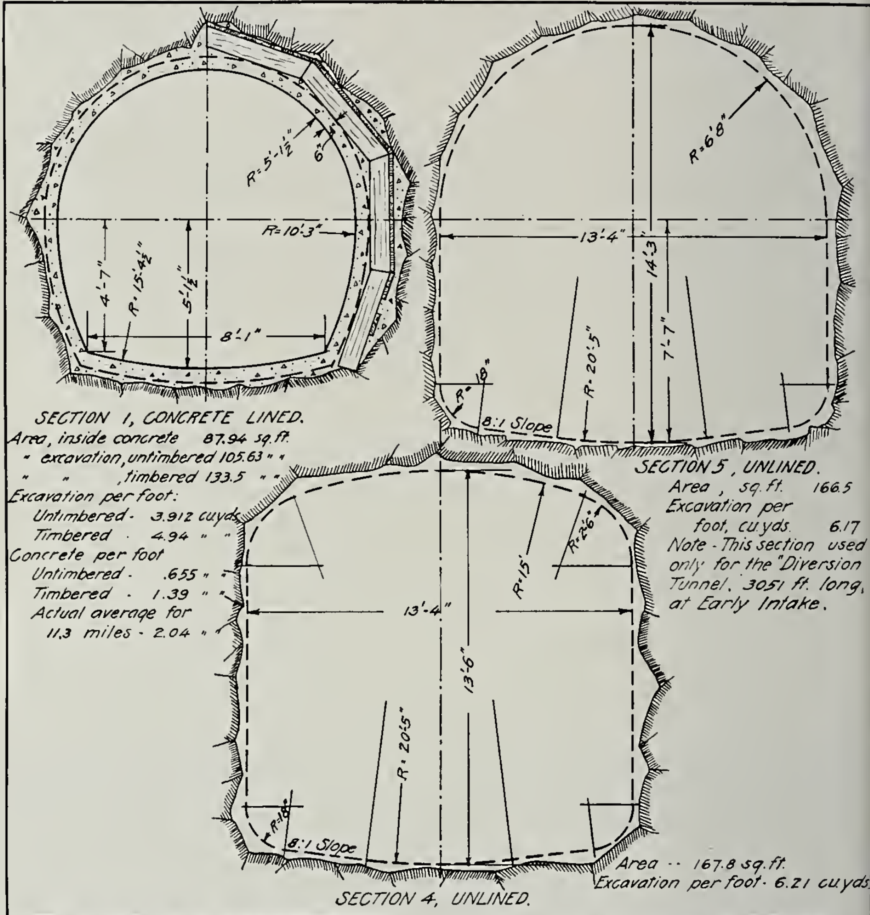
Scouring chambers with discharge conduits through the dam are provided in front of the fixed grillage at the gate house to release debris and other refuse. Surplus waters not diverted into the aqueduct here pass over the spillway to continue on down the river to be intercepted about 40 mi. below by the Don Pedro reservoir of Turlock and Modesto Irrigation Districts. The cost of the diversion works, including dam, spillway, headworks, and appurtenances, is about $570,000.

AQUEDUCT MOUNTAIN DIVISION

The mountain tunnels extend 19 mi. from Early Intake to Priest reservoir. The tunnel is generally of horseshoe shape, 10 ft. 3 in. diameter. The first half-mile of tunnel skirting under the granite canyon wall is 14 ft. 3 in. high by 13 ft. 4 in. wide with top arched to 6 ft. 8 in. radius, bottom to 20 ft. 5 in. radius and with 166.5 sq. ft. neat excavation. This tunnel, known as the diversion tunnel, is unlined except for a few short stretches. The next 7 mi., in solid granite, is excavated to 13 ft. 6 in. high by 13 ft. 4 in. wide, with top arched to 15 ft. radius and bottom to 20 ft. 5 in. and is not lined. It has a neat area of 167.8 sq. ft.

Near Mile 5 the tunnel is interrupted by 225.5 ft. of 9.5 ft. diameter riveted steel pipe, which carries the flow across South Fork of Tuolumne River. This pipe is a continuous beam of four unequal spans, the longest being 74 ft. across the main channel. It is supported on concrete piers with reinforcement extending into holes drilled in the bed-rock. An expansion joint is introduced at the point of contraflexure nearest the upstream anchor. The pipe is encircled by angle-iron stiffeners to prevent flattening and is covered with heavy timber to prevent damage from stray rocks falling from the cliffs above. In addition to the usual asphaltic coating the pipe is painted with an aluminum preparation to minimize expansion and contraction due to changes of temperature.

The remainder of the tunnel, about 11.5 mi., is lined throughout with 1:2¼:4½ concrete with minimum thickness of 6 in. It is of horseshoe shape 10 ft. 3 in. in diameter with 87.94 sq. ft. neat area inside of lining. The rock encountered consists of diorite, quartzite, slate, and amphibolite



HETCH HETCHY WATER SUPPLY OF THE CITY AND COUNTY OF SAN FRANCISCO, CALIFORNIA

STANDARD TUNNEL SECTIONS
USED IN
HETCH HETCHY AQUEDUCT

DEPARTMENT OF PUBLIC WORKS. APPROVED M.M. O'Shaughnessy CITY ENGINEER
BY LCC TRACED LCC CHECKED RPMC
SCALE ¼ inch = 1 foot DATE June 9, 1925

A 282

schist. The tunnel with a grade of 0.00155, or about 8 ft. per mi., was designed for capacity of 620 second ft. but under certain favorable operating conditions may carry one-sixth extra capacity.

Excavation was carried on from 12 working faces, 4 of which were portals, 4 from adits and 4 from the bottoms of two shafts. Big Creek shaft was 646 ft. deep and Second Garrote shaft, 786 ft. Haulage in the tunnels was by electric storage battery locomotives. Electrically-operated mucking machines were used for loading materials in all headings except from the shafts, which were too small to allow convenient passage of the electric machines. At these headings smaller, air-operated mucking machines were used. At Second Garrote shaft where excessive amounts of water, as high as 2,000 gal. per minute, were encountered, a steam-driven air compressor was maintained as a reserve or standby service to insure against possible failure of electric power supply with consequent drowning of the shaft. The rate of progress varied according to the ground encountered, from 300 ft. to 700 ft. per month. The best monthly progress, 776 ft., made from Priest Portal, in August, 1921, established a new United States speed record up to that time, for driving hard rock tunnel of this character. Cost of the mountain tunnels is about $11,400,000.

AQUEDUCT, MOCCASIN DIVISION

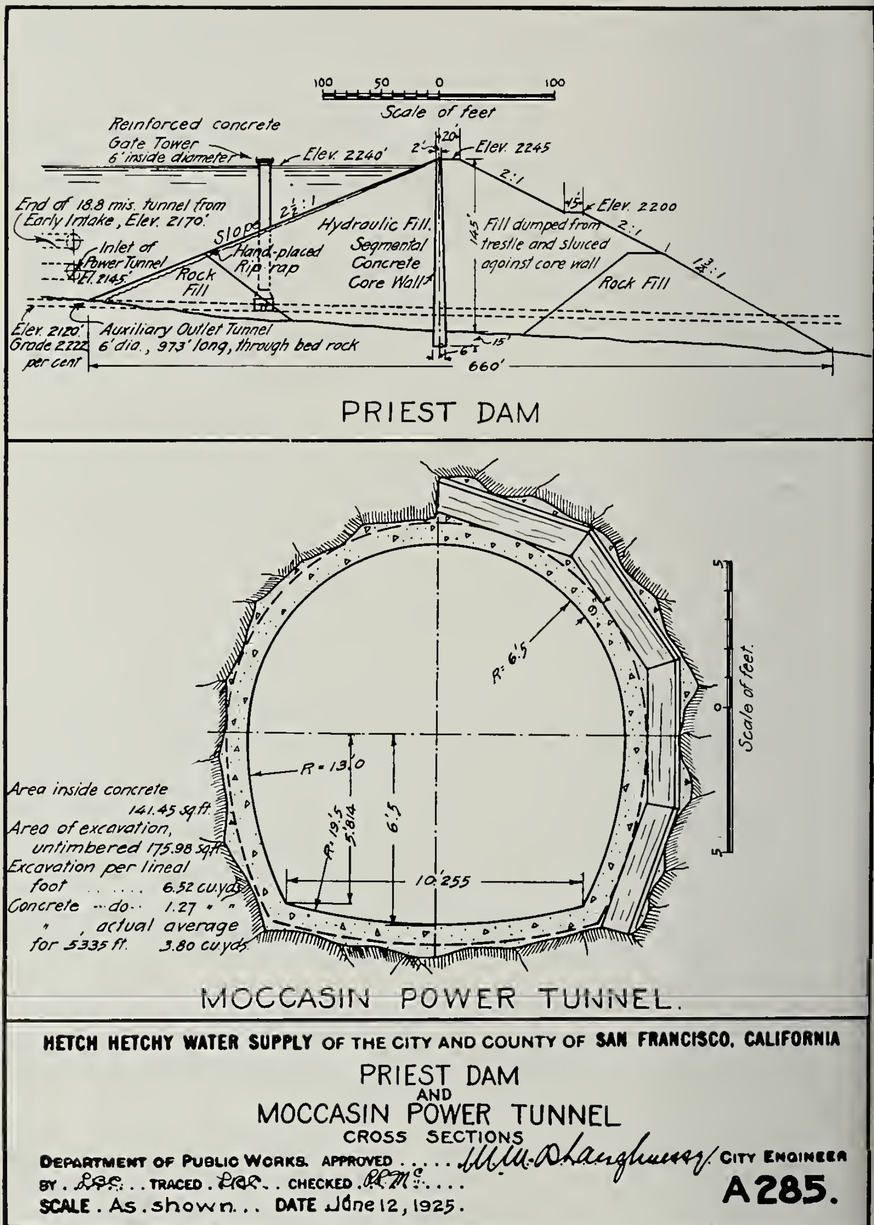
Priest Regulating Reservoir:

At the west end of the mountain tunnel at elev. 2,169 ft. the water enters Priest reservoir, which was created to provide forebay capacity for flexible operation of Moccasin power plant. Its function is to regulate the flow of water which it receives at a constant rate of 620 second ft. or better, and may discharge at a variable rate ranging from nothing to 1,240 second ft. through Moccasin power tunnel according as the governors automatically allow a greater or a lesser amount of water to pass through the water wheel nozzles as the demand for power increases or decreases.

In July, 1914, the City Engineer received a report from a consulting board of engineers, Professors Wm. F. Durand, J. D. Galloway and F. G. Baum, on the arrangement of the forebay and power drop at Moccasin, the suggestions in which were very generally followed.

The forebay reservoir, made by constructing an earth fill dam across Rattlesnake Creek, has capacity of 2,350 acre ft., or two days' full flow of the aqueduct.

The dam is 1,160 ft. long, 147.5 ft. high, with crest elev. 2,245 ft. The base is 660 ft. thick. The dam contains 717,283 cu. yd. of earth and rock fill and 17,043 cu. yd. of concrete in the core wall, which extends 15 ft. deep into bed-rock. To provide a certain degree of flexibility the core wall is divided into panels 50 ft. long by 16 ft. high, which dovetail and are sealed with water stops of 16-gauge sheet copper in the joints between panels. About 27 tons of copper are used for this purpose. The embankment consists of rock spoil from the tunnels placed in the upstream and downstream toes,



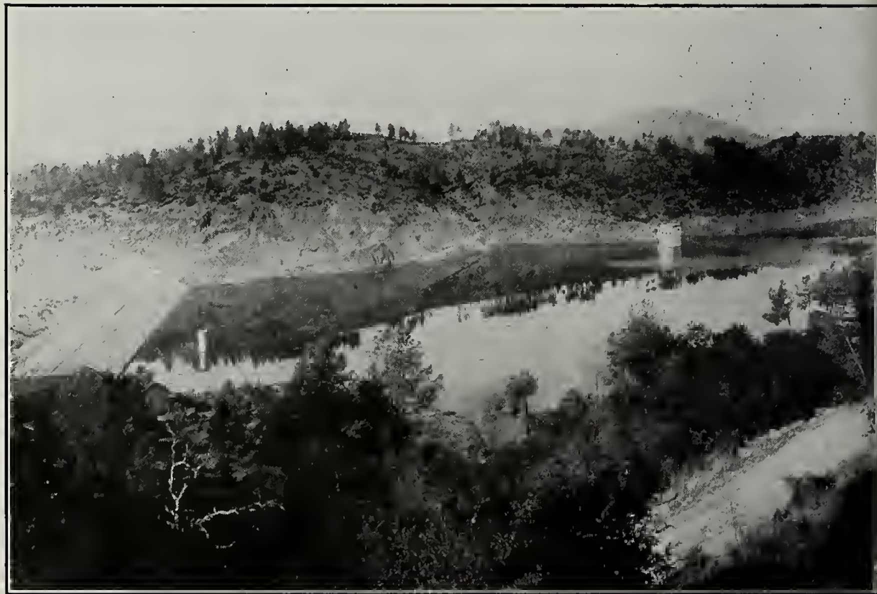
Scale of feet
Reinforced concrete Gate Tower 6' inside diameter
Elev. 2240'
Elev. 2245
End of 18.8 mis. tunnel from Early Intake, Elev. 2170'
Inlet of Power Tunnel El. 2145'
Slope 2½:1
Hand-placed Rip-rap
Rock Fill
Hydraulic Fill.
Segmental Concrete Core Wall
145'
Fill dumped from trestle and sluiced against core wall
Elev. 2200
Rock Fill
Elev. 2120'
Grade 2.222 per cent
Auxiliary Outlet Tunnel 6' dia., 973' long, through bed rock
660'
PRIEST DAM
R: 6.5
R = 13.0
R: 19.5
5.814
6.5
10.255
Scale of feet.
Area inside concrete 141.45 sq.ft.
Area of excavation, untimbered 175.98 sq.ft.
Excavation per lineal foot ...... 6.52 cu.yds.
Concrete --do-- 1.27 " "
" , actual average for 5335 ft. 3.80 cu.yds.
MOCCASIN POWER TUNNEL.
HETCH HETCHY WATER SUPPLY OF THE CITY AND COUNTY OF SAN FRANCISCO, CALIFORNIA
PRIEST DAM
AND
MOCCASIN POWER TUNNEL
CROSS SECTIONS
DEPARTMENT OF PUBLIC WORKS. APPROVED ..... M.M. O'Shaughnessy CITY ENGINEER
BY . L.B.C. . . TRACED . R.B.C. . . CHECKED . R.C.M.C. . . .
SCALE . As shown . . . DATE June 12, 1925.
A285.

earth fill in the upstream zone placed by hydraulic methods, and earth fill in the downstream section placed by dump cars from steam shovel and sluiced into place by water jets. The slope of the upstream face is 2½ to 1; of the downstream face 2 to 1, except the rock toe, which is 1¾ to 1. The upstream face is covered with hand-placed riprap to prevent erosion from wave action. A concrete lined spillway 40 ft. wide with lip at elev. 2,240 protects against overtopping. An auxiliary outlet and drainage tunnel to act as a scouring chamber, 6 ft. in clear diameter with inlet at elevation 2120, was driven through the solid rock of the east abutment and lined with 12 in. of concrete. Valves in this tunnel are reached by a vertical, circular, concrete tower of 6 ft. inside diameter. The tunnel and tower contain 1,954 cu. yd. of concrete. This dam was completed in 18 months by day labor employees under the direction of the City Engineer, at a cost of approximately $1,000,000.

Moccasin Power Tunnel:

Water discharging from the reservoir to the power house enters Moccasin power tunnel at elev. 2,145 through a concrete control tower, oval in plan, 65 ft. by 36 ft., inclusive of a semicircular, precast, screen rack projecting into the reservoir. The structure contains 2,765 cu. yd. of 1:2:4 concrete. Six electrically-operated sluice gates, each 6 ft. by 8 ft., provide for cutting off water to the tunnel. Manual operation is also possible and steel shutters are provided for isolating any set of gates for repairs, if necessary. Fixed screens with manually operated cleaner prevent fine trash from entering the tunnel.

PRIEST DAM, UPSTREAM FACE



PRIEST REGULATING RESERVOIR

The tunnel begins as the frustum of an oblique cone tapering from about 19 ft. width and height to the 13 ft. standard horseshoe section in a distance of 30 ft. The tunnel section is 141.47 sq. ft., with grade of 6 ft. per 1,000, making its capacity 1,240 sec. ft. without excessive loss of head. The minimum thickness of concrete inside of timbering is 9 in. and the concrete averages 3.8 cu. yd. per lineal ft. Total concrete and grout is 21,000 cu. yd. Material encountered was andesite and amphibolite schist, part of which was crushed for concrete rock and part used for the riprap face on Priest Dam. The tunnel extends 5,370 ft. to the inside wall of a surge shaft 40 ft. in diameter, which serves as a manifold for the three penstock pipes, which are imbedded in concrete in tunnel 535 ft. long, leading from the opposite side toward the power house. The cost of the power tunnel, inclusive of inlet tower and surge shaft, is approximately $1,340,000.

Surge Shaft:

The surge shaft, of reinforced concrete, is designed to handle surges of from 35 to 40 ft. The floor is at tunnel grade, elev. 2,112, and the height to the rim is 160 ft. It projects 48 ft. above the surface of the ground. The walls of this portion range in thickness from 24 in. to 10 in. and contain heavy reinforcement, the maximum of which is 2 rings of 1½-in. square bars staggered at 7 in. centers. Accumulation of external water pressure below the ground surface which might result from saturation from surface runoff, is prevented by a system of porous cement drain tile. The shaft contains 2,185 cu. yd. of 1:2:4 concrete.

Penstock Pipes:

The three penstock pipes, the horizontal length of which is 5,349 ft., begin at the wall of the surge shaft, each as the frustum of an oblique cone with large diameter 12 ft. 4 in. The smaller end connects to the 104 in. diameter riveted steel pipe. About 50 ft. westerly from the tunnel portal in each line a 104-in. diameter butterfly valve has been installed. The most southerly pipe is dead-ended at the valve pending future extension when two more generators shall have been installed in the power house. The butterfly valves are motor operated and arranged for closing by remote control from the power house. As a matter of precaution the opening control is at the valve only. Two sets of four 8-in. air valves are installed in each line immediately below the valves.

At elev. 2,070 the pipe diameter reduces from 104 in. to 98 in. At a slope distance of 2,111 ft. the pipes branch each into two 66-in. diameter pipes with hammer forge welded shop joints and with bumped, riveted, field joints of enlarged section. Above the branch are two additional sets of four 8-in. air valves. The welded pipes, the slope length of which is 3,469 ft., range in diameter from 66 to 54 in. Immediately before entering the power house they branch again, each into two 36-in. diameter pipes on which are hydraulically operated 36-in. gate valves. The total weight of pipe is 6,200 tons.

MOCCASIN SURGE SHAFT AND PENSTOCK PIPES

All pipes are supported on concrete piers or saddles which were built in advance of the pipe laying. At angles, of which there are 20, either horizontal, vertical or combined, the pipes are held securely by concrete anchors, the largest of which contains 839 cu. yd. of concrete and 7.64 tons of reinforcing steel. Expansion joints are provided between anchors. At the 98 by 66-in. Y branch is a special sliding anchor in which the upper portion, including the pipes, can slide on cast iron plates imbedded in the fixed concrete of the lower portion.

The cost of the penstock lines is approximately $2,456,000.

MOCCASIN POWER PLANT

This power plant, the largest of the Hetch Hetchy system, uses the full flow of the aqueduct, 620 sec. ft., dropping 1,316 ft. from 2,240 ft., the elev. of high water in Priest Reservoir, to 924 ft., the elevation of the water wheel nozzles.

The power house, as at present built for four units, is 225 ft. long, 98 ft. wide and 67 ft. high. It is a steel frame building, with massive concrete foundations resting on bed-rock and with reinforced concrete walls. The architecture is of the California-Spanish style, which is particularly suited to the site. This building houses the generators and low voltage switching apparatus, but the step-up transformers, high tension switches and high tension buses are installed in the rear, out-of-doors, at the easterly side of the building. The buses are carried on a structural steel frame. The 11,000-volt, 3-phase, 60-cycle current generated, is stepped up to 115,000 volts for transmission to San Francisco. All apparatus, however, is designed for ultimate operation at 154,000 volts.

The water wheels, of the double overhung impulse type, operate at 257 r. p. m. Each has a rated output of 12,500 h. p. or 25,000 h. p. for the unit. The rotating part of each unit weighs 118 tons and can be handled by the 135-ton overhead crane installed in the power house. The water wheel rating is based on an effective head of 1,250 ft. The maximum jet diameter is 11 in. An auxiliary relief needle nozzle is set directly beneath the main nozzle and connected therewith in such manner that it may be operated as a synchronous bypass, or may be set to close automatically to save water.

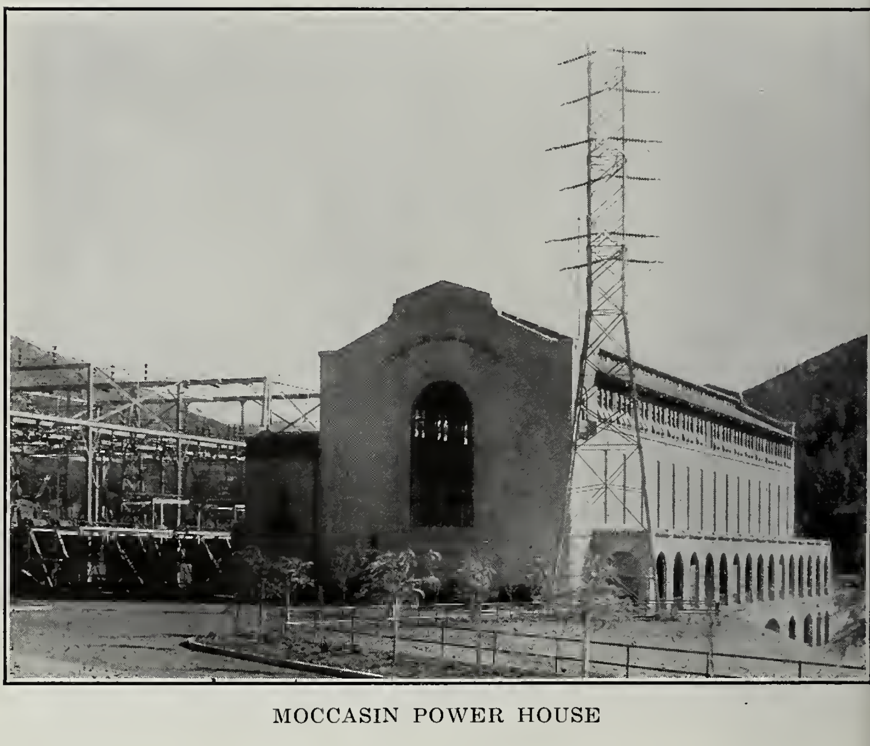
The rating of the generators is 20,000 kv-a. These generators deliver 11,000 volts directly to the transformers, the arrangement of the power house being such that so far as practicable the generators and the transformers operate together as a unit, provision being made for but one 11,000-volt bus which can be used to connect any generator to any bank of transformers in an emergency. From this 11,000-volt bus all auxiliary power is taken for use in the operation of the station and for two 22,000-volt circuits for construction work along the aqueduct line.

MOCCASIN RE-REGULATING RESERVOIR, POWER PLANT AND VILLAGE

The transformers are single phase, 6,667 kv-a capacity, with taps which permit of their being operated at either 11,000 to 115,000 volts, or 11,000 to 154,000 volts. They are set out-of-doors in banks of three; complete piping connections are provided for circulating water and for oil filling and filtering. Tracks and transfer cars permit of any transformers being moved into the power house under the crane for repairs. The cost of the power house, inclusive of machinery, is about $2,400,000.

POWER TRANSMISSION LINE

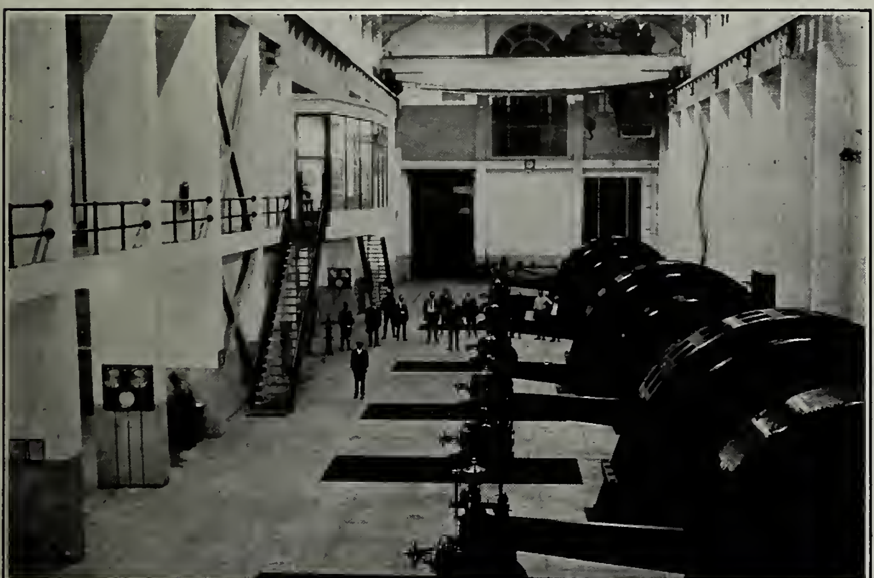
From the switching station behind the power house eventually four 154,000-volt circuits will be carried to San Francisco on two double circuit steel tower lines. At present one double circuit line has been built to Newark on San Francisco Bay, a distance of 98½ mi. from the power house; 506



MOCCASIN POWER HOUSE

towers are employed in this distance—an average spacing of 1,000 ft. They are placed 20 ft. south of the northerly boundary of a 110-ft. right of way strip, to be supplemented in the future with a similar line on the southerly side. The distance between lines is 24 ft. at the top arm, 28 ft. at the middle arm, and 24 ft. at the bottom arm. The vertical spacing between conductors is 15 ft. The lowest cross-arm is 62 ft. above the ground. The conductors from the power house to a point within a few miles of the bay are 397,500 c. m. steel reinforced aluminum conductors. From the point where bay fog is encountered, hemp cored copper conductors are used. These have a c. m. capacity of 345,000 with an external diameter of ¾ in. At suspension points, 10 units of Westinghouse No. 601 insulators are used, while at dead-end and other points of stress, 12 Westinghouse No. 631 insulators are employed. Vibration dampers have been installed on the entire line.

Operation of the present two circuits in parallel, as will normally be the case, will permit of transmitting the power generated at the Moccasin plant with a line loss of approximately 8 per cent, and when one line must be taken out of commission temporarily, the remaining circuit will still have



MOCCASIN POWER HOUSE WATER WHEELS AND GENERATORS

capacity to transmit the output of the plant to San Francisco. The cost of the transmission system is approximately $1,800,000.

Upon construction of the two future plants near Early Intake, the installed capacity at the Moccasin plant will be increased from 100,000 to 150,000 h. p. so that this plant may be used for all regulation of the system.

AQUEDUCT FOOTHILL DIVISION

This unit extends 16.3 mi. from the tail-race of Moccasin power plant to the easterly edge of San Joaquin Valley above Oakdale and comprises Moccasin Dam, the Foothill tunnels and the Red Mountain Bar pipe line.

HETCH HETCHY POWER TRANSMISSION LINE CROSSING SAN JOAQUIN RIVER

Moccasin Dam:

The flow of water discharged from Moccasin power house varies greatly throughout the day in proportion to the demand for electrical energy, and since the flow in the aqueduct beyond this point for water supply purposes must be at an approximately uniform rate, it was desirable to construct a tail-race reservoir of about 500 acre ft. (160 m. g.) to regulate the differences in flow, reversing the function of the Priest forebay reservoir.

A reservoir was made by construction of a dam across Moccasin Creek about 1,500 ft. downstream from the power house. The watershed of Moccasin Creek tributary to this reservoir consists largely of cattle ranges and during future delivery of water to San Francisco it is planned to bypass this local polluted water by construction of an upstream dam and completion of a bypass conduit already begun, which will lead the water from the upper dam through the reservoir to be released below the lower dam. An auxiliary outlet tower may be used to drain the reservoir through the bypass conduit.

The present dam is 855 ft. long and 50 ft. high, with crest at elev. 927. The central portion is earth fill while both upstream and downstream toes are rock fill. Total embankment is 143,341 cu. yd. The core-wall is monolithic reinforced concrete with thickness varying from 14 in. to 18 in. Beneath its base, which is 4 ft. thick, the slate foundation was thoroughly grouted. The core wall contains 3,600 cu. yd. of concrete.

The spillway is of the overflow type, with 9,000 sec. ft. capacity. Its lip at 911 ft. elev. sets the storage at 114 m. g. Eventually automatic gates will be installed to hold the normal water surface at 920 ft. elev. and provide storage of 205 m. g. or 630 acre ft.

The flow from the reservoir through the main outlet tower to the aqueduct tunnel is controlled by two 6 ft. by 8 ft. 6 in. electrically operated slide gates in a reinforced concrete tower directly over the tunnel portal.

The dam and appurtenances including diversion of streams, were completed in 1930 at a cost of approximately $640,000.

Foothill Tunnel:

From this reservoir a tunnel leads westerly to the edge of the San Joaquin Valley, a distance of 15.8 mi. Tunnel invert elevations are 881 ft. at inlet and 747 ft. at outlet. This tunnel 10 ft. 3 in. diameter with a fall of 8½ ft. per mi., the same as the mountain tunnel, has a capacity in excess of 400 m. g. d. At a point 5.2 mi. westerly from the reservoir the tunnel emerges to the canyon wall of Tuolumne River, which is crossed by the Red Mountain Bar pipe line 0.5 mi. in length, which will be described below. The foothill tunnel is of approximately the same characteristics as those of the mountain tunnel already described.

Upon the beginning of construction, day labor employees, under direct charge of the City Engineer, installed all the necessary appurtenances, such as water systems, power and telephone lines, roads and camps and all necessary construction plant. This was followed by their driving about 1,000 ft.

of tunnel in each heading so that contractors who intended bidding on the work might observe the character of material and be given every opportunity to understand the conditions so that they would not have to include excessive amounts for unknown hazards.

Upon receipt of bids it was considered advisable to let about half of the tunnel work by contract and to do the remainder by day labor employees. A keen rivalry sprang up between the day labor employees of the City and the contractors' forces, which resulted in exceptional progress being made. Three times the day labor employees broke existing records for speed in driving tunnel, establishing a final record of 803 ft. of advance in the month of September, 1927. The costs of driving were $35.53 per ft. by day labor crews, as against $40.49 by the contractors' forces. In placing concrete lining the cost by day labor was $36.11 per ft., as against the contractors' $47.38 per ft. The total cost of these tunnels was approximately $8,000,000.

Two overflow shafts were constructed on this tunnel, one at the easterly side of Red Mountain Bar crossing and the other near Oakdale portal.

Red Mountain Bar Pipe Line:

The canyon of Tuolumne River at Red Mountain Bar is flooded during periods of high water in Don Pedro reservoir of Turlock and Modesto Irrigation Districts so that it was necessary to lay the pipe across the river before the level of water should rise above this point. In trench blasted in the bed-rock of the river bottom, 770 ft. of 9½-ft. diameter, riveted steel pipe was laid and covered with concrete from 18 in. to 2 ft. in thickness. The interior of the pipe was lined with cement mortar 1½ in. in thickness. To do this work it was necessary to divert the flow of the river, which was done by construction of a coffer-dam half way across the river until the work within it was completed. The same method was then followed for the other half. The diversion of the river was interesting in that it uncovered relics of the placer mining days of the 60's. The pipe was completed in 1923, prior to completion of Don Pedro Dam of the Turlock and Modesto Irrigation Districts, which submerged it to a depth of 100 ft. Cost of the work was approximately $300,000.

To carry out the adopted plan of bringing in a portion of the Hetch Hetchy water supply by June, 1932, the Red Mountain Bar pipe line is now being completed. The work consists of two extensions of the present pipe, one of 918 ft. on the east side of the river and one of 826 ft. on the west side to connect to the existing tunnel portals. On the easterly canyon wall there will be a concrete sand trap. On the west side at the tunnel inlet there will be an overflow structure.

Plans have been prepared for a power plant at this point to use the surplus water not required in San Francisco during the earlier years of the operation of the aqueduct. Such a plant could be built for approximately $1,000,000 and would return an annual revenue of almost $500,000.

AQUEDUCT SAN JOAQUIN PIPE LINE

There is now under construction a pipe line 47½ mi. in length across the San Joaquin Valley from Oakdale Portal at elev. 747 ft. to Tesla Portal at elev. 399 ft. Oakdale Portal is in Tuolumne County about 4 mi. southeast of Knight's Ferry, and Tesla Portal is in San Joaquin County about 7 mi. south of Tracy. Eventually the Hetch Hetchy aqueduct across the valley will consist of three pipes 6 ft. or greater in diameter, but economic studies indicate the desirability of initial construction of a 5-ft. pipe with capacity of 60 m. g. d. Until recently it was planned to defer beginning of construction of this present pipe line until such time that it and the Coast Range tunnel might be completed simultaneously at the end of 1933.

However, due to a succession of dry seasons which have resulted in depletion of the local reservoir system supplying water for San Francisco's needs, it has been decided to rush construction of this pipe line and to do certain other work, which will be described elsewhere, so as to bring Hetch Hetchy water into the city at an earlier date, say by the middle of 1932.

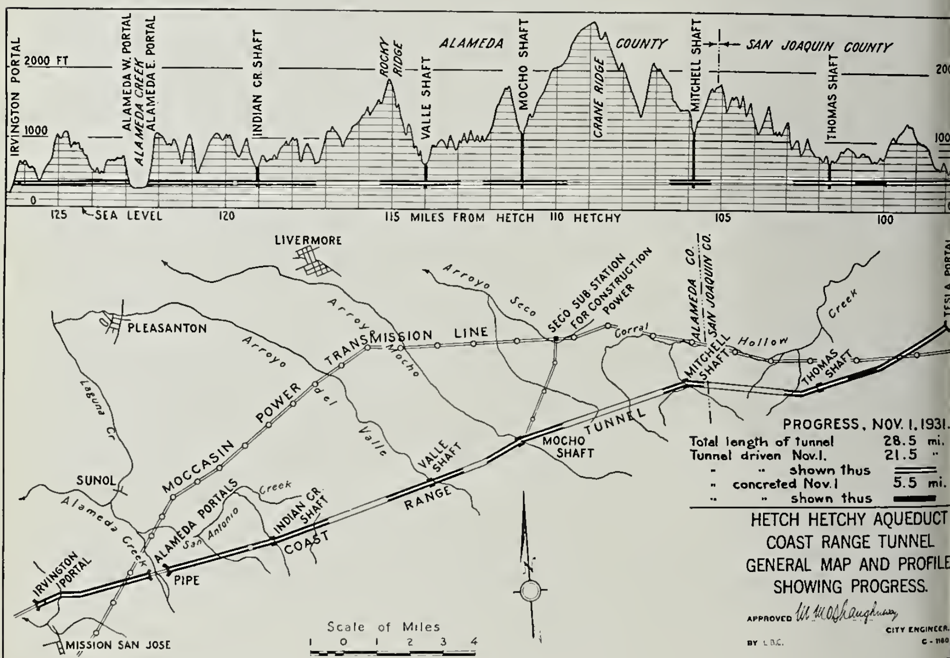
Contract was awarded May 22, 1931, to Youdall Construction Company in the estimated amount of $4,136,479 for construction of San Joaquin pipe line, to be completed June 10, 1932. The line consists of welded steel pipe with diameter varying from 56 in. to 66 in. and thickness from 5/16 to ½ in. The total amount of steel is approximately 40,000 tons. Bidders were allowed the option of riveted, lock bar, or welded pipe, and of concrete pipe for a short section under lighter head near Tesla Portal, but all bids were for welded pipe. All shop seams are welded, but the contractor is using his option to rivet the circumferential field joints. At the crossing of San Joaquin River and at Elliott Cut, both of which are classed as navigable streams, the pipe is depressed below stream bed, the bottom being 15 ft. below low water surface, and rests on concrete saddles supported by timber piling. It is encased in a reinforced concrete jacket 6 in. thick, poured in place with the pipe under pressure and is lined internally with cement plaster of minimum thickness of 1½ in. This river crossing work required the construction of two cofferdams similar to the work done at Red Mountain Bar crossing.

As a result of soil surveys several different types of pipe protection are used. All pipe is dipped in a hot asphaltic bath to receive a coating with final thickness of at least 1/16 in. In the dry non-corrosive soil, additional protection is given by wrapping the pipe with 40-lb. asphalted felt. In slightly corrosive soils or in locations that although dry now may later, if placed under irrigation, develop corrosive properties, the felt wrapping is supplanted by a ½-in. coating of 12 sk. per yd. cement mortar with wire mesh insertion. In the very wet land at and adjacent to the river crossing, an area that eventually may be submerged by any plan of state water conservation, the concrete envelope is 2 in. thick, except that where the external load is heavy this thickness is increased to 6 in. and the pipe rests on concrete saddles on pile bents.

AQUEDUCT, COAST RANGE TUNNEL

The Coast Range division of the aqueduct extends from Tesla portal, at 399 ft. elev., the end of the San Joaquin pipe line, 29.1 mi. in a general westerly and southwesterly direction to Irvington portal, at elev. 316 ft., near Mission San Jose. It consists of a 25-mi. continuous tunnel, the longest ever attempted by man, and a 3.5-mi. tunnel separated by a pipe line 0.6 mi. in length across the valley of Alameda Creek.

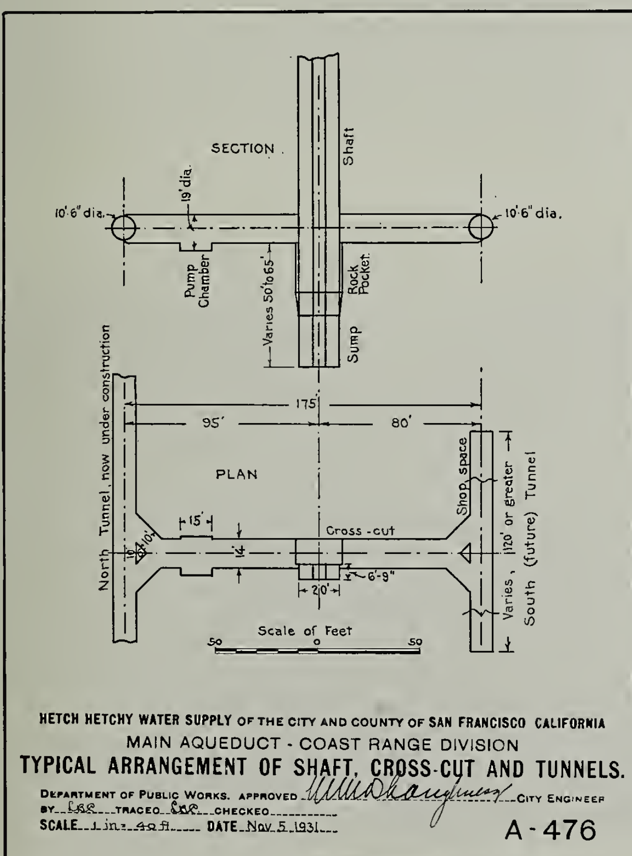
The finished tunnel is a 10 ft. 6 in. diameter circle with concrete lining varying in thickness from 6 in. to 2 ft. Although this tunnel has approximately the same cross-section area as the tunnels heretofore constructed, it is built on a flatter grade (about 3 ft. per mi.) and will have a capacity of 250 m. g. d. On this flatter grade it would be necessary to make the tunnel about 13 ft. in diameter to carry the same flow as the mountain and foothill tunnels. An alternative method was to construct the tunnel in installments, making one tunnel 10 ft. 6 in. in diameter now, to be paralleled in future with a similar tunnel. Under future operating conditions each of these tunnels would have a normal capacity of 200 m. g. d. Under proper operating conditions now the capacity of one tunnel may be made 250 m. g. d. It does not appear probable that this capacity will be necessary for municipal use within 25 years. The saving in cost in now constructing the smaller tunnel, as against the larger tunnel, with future interest accumulations, will be far more than sufficient to construct a second parallel tunnel at a future date.



It was therefore determined to construct at this time a first tunnel 10 ft. 6 in. in diameter and to parallel it in future with a similar tunnel, 175 ft. south of the present one.

In the 25-mi. tunnel five shafts were sunk from depressions at the surface down to the tunnel grade. The shafts are midway of the right of way and from each shaft a cross-cut is driven, north 95 ft. and south 80 ft. to the respective center lines of the present tunnel and the future tunnel. The shafts and cross-cuts are concrete lined, so as to be available for the future work. From the north end of the cross-cut the present tunnel is driven both east and west. To date, October, 1931, the aggregate length of tunnel driven from various shafts and portals is 21.5 mi. out of a total length of 28.5 mi. and it is expected that the longest section, that between Mocho and Mitchell Shafts, 5.2 mi. in length, will be completed in 1933.

The plans of this department called for beginning of work in the winter of 1925 but the budget for the work was not approved by the Board of



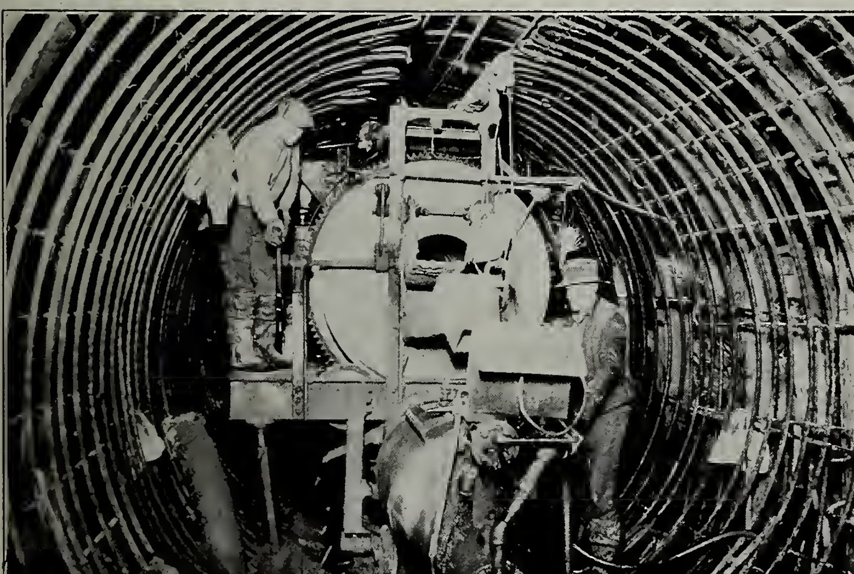
Supervisors until early in 1927. Work began immediately upon approval of the budget. In the fiscal year 1927-28 2,245 ft. of shaft sinking was accomplished. During the next fiscal year 1928-29 the shafts were completed, 12 of the 14 tunnel faces were opened and 4.1 mi. of tunnel driven. During the fiscal year 1929-30, although some of the headings were shut down pending sale of bonds to finance the work, the tunnels were advanced 8.5 mi. In the month of June, 1930, almost 1 mi. of tunnel was driven. In July, 1930, the work received a severe setback from an unforeseen gas explosion in which 12 men lost their lives. As a result of extra safety methods put into effect at this time, and due also to holing through two headings, the annual progress in 1930-31 was 7.2 mi. Excavation has been completed in two of the seven sections, one of 4½ mi. and one of 3½ mi., and these two sections are now being lined with concrete.

The location of the tunnel follows generally along the "Freeman Plan," but as a result of detail geological studies, aided by diamond drill borings, the tunnel line was shifted to the south to minimize the length which it was necessary to drive through geological formations in which there was a possibility of intercepting dangerous gases, particularly methane. Safety measures in common use in similar mining work were initiated in this tunnel and were strictly observed. Nevertheless the fatal explosion occurred. Several investigations of the accident were made and at the inquest held by the Coroner of Alameda County, the City was exonerated from all blame.

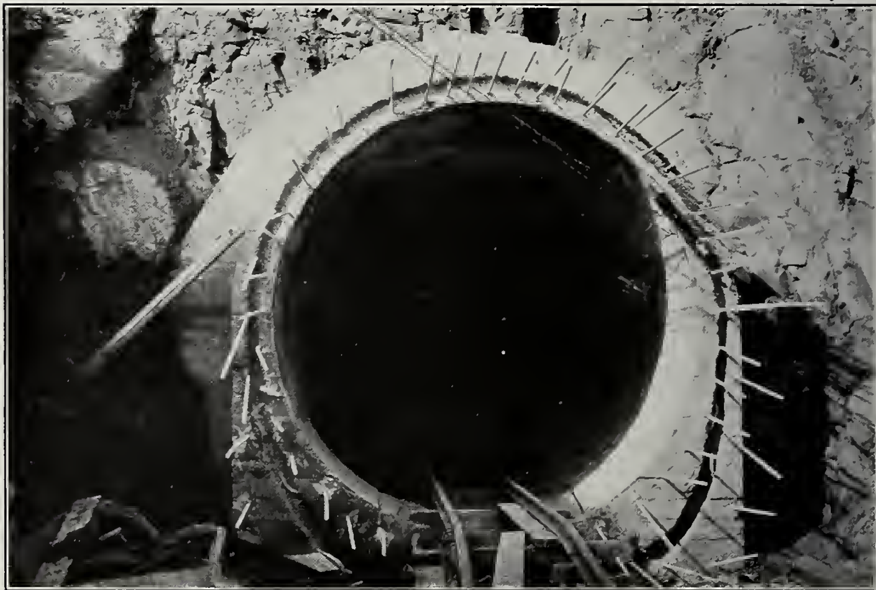
Additional safety methods were adopted. Among these was the use of "permissible" locomotives, such as had never before been used west of the

TYPICAL TUNNEL TIMBERING

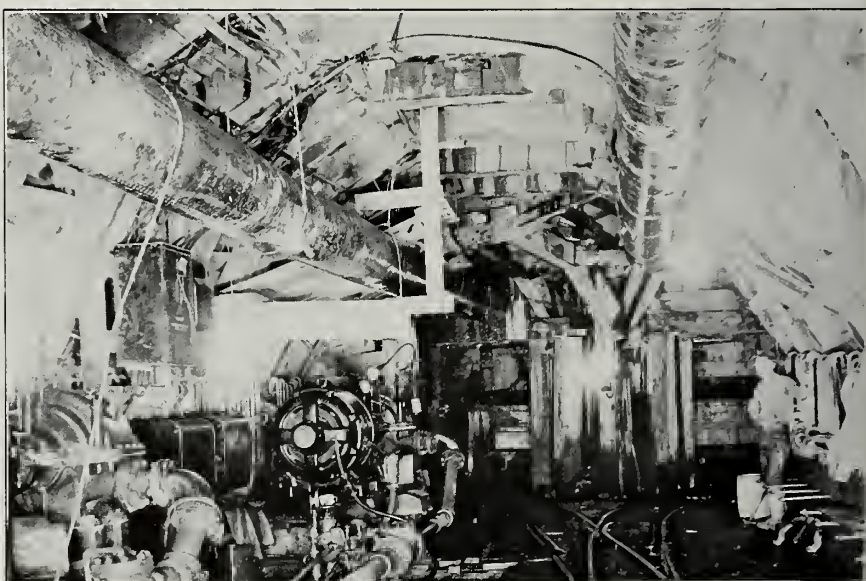
PLACING GUNITE CONCRETE LINING IN 10 FT. 6 IN. DIAMETER TUNNEL



MIXER AND GUN PLACING CONCRETE IN CIRCULAR TUNNEL



PORTAL OF 10 FT. 3 IN. DIAMETER TUNNEL



STATION AND CROSS-CUT AT MOCHO SHAFT, COAST RANGE TUNNEL

Rocky Mountains. Excavation was discontinued partially for a period of three months while these locomotives were being manufactured and delivered. During this period mules and horses were used for hauling muck-cars. Upon resumption of work, the additional safety methods resulted in further delay. Consequently, the tunnel work will not be completed in 1932 as originally planned and the construction costs will be increased by a sum difficult to estimate, but amounting to more than $1,000,000. The physical difficulties in driving this tunnel have been numerous and the overcoming of these difficulties has reflected great credit on the staff of engineers and superintendents engaged in the work.

All of the machinery on this tunnel construction is operated with electricity as the primary source of power. The most convenient source for this power is the main Hetch Hetchy transmission line from Moccasin to Newark which parallels the tunnel work. At a site on Arroyo Seco, nine miles southeast of Livermore, a 2.8-acre tract of land was purchased and a substation erected. This station takes power from either of the two high-voltage circuits and steps it down from 102,000 to 22,000 volts, which was determined as the most satisfactory voltage for transmission along the aqueduct. The energy passes through a bank of three 2,000 kw. single phase transformers. A fourth transformer is provided as a spare. From these transformers a 30-mi. transmission line consisting of two 3-phase 22-kv. lines transmits the power to the various camps along the tunnel route.

Substations with capacity of 600 kv-a were installed at the shaft camps. At portal camps the installation is 300 kv-a. In these stations the transformers step down the power to 3-phase 440-volt power current and 110-220-volt lighting current.

Geologically considered, the tunnel has been of extreme interest in the fossil remains discovered in the Tesla-Thomas section, among which are an ammonite whose age is estimated at 33,000,000 years, teeth of the three-toed horse, and an elephant's foreleg. In one section of the tunnel, 5,401 ft. east of Valle shaft granite was penetrated, the first time that this rock has been encountered in this section of the Coast Range.

The observance of safety rules in the tunneling operations is supervised by C. H. Fry, Superintendent of Safety of the Industrial Accident Commission of the State of California. Mr. Fry is in constant contact with the work and well qualified to comment thereon. We quote from a recent letter over his signature:

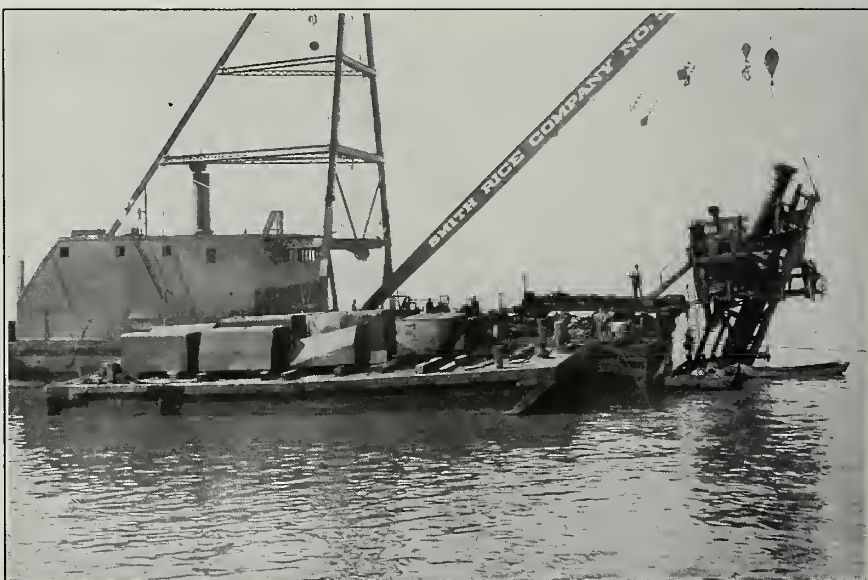
"I have endeavored to give you just a slight understanding of the difficulties that have been encountered as there have been so much injustice and unfair criticism of the progress which has been made in these tunnels. I believe that had these tunnels been started on a contract that the contractor would soon have thrown up his contract and the bonding company would have forfeited the bond, rather than to attempt to complete the contract. I trust that some day there may be a complete report of this project made and credit given to the men who have worked so hard and under such unusual and difficult conditions with their only reward to date of unjustified, adverse criticism."

AQUEDUCT BAY CROSSING DIVISION

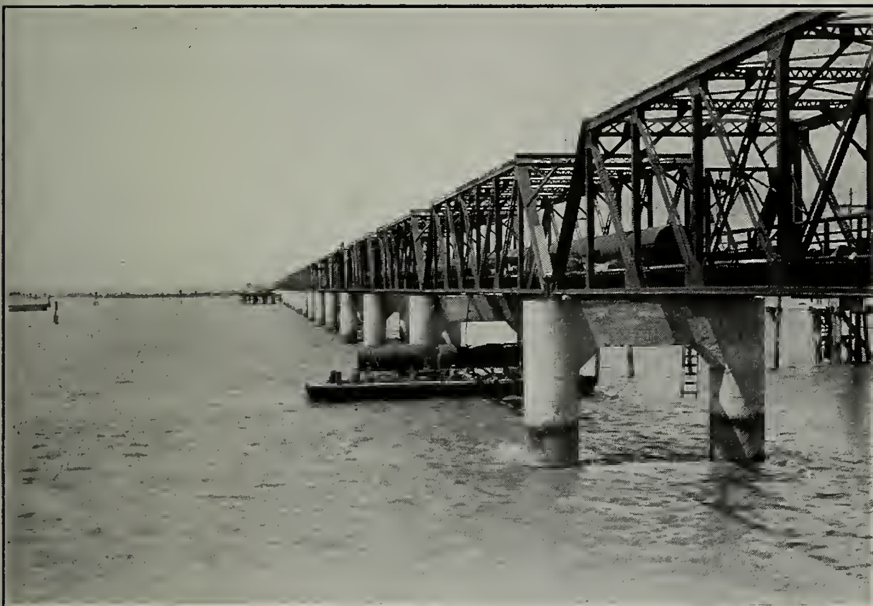
Pipe Line:

From the foothill tunnel the aqueduct continues as a pipe line 5 ft. in diameter and 21 mi. long, crossing San Francisco Bay and terminating in Pulgas Tunnel 1¾ mi. long, which discharges at elev. 290 ft. into Crystal Springs Reservoir in San Mateo County, 2 mi. south of the concrete dam. The pipe is 5 ft. diameter riveted steel except at navigable crossings where 42 in. diameter submerged, flexible joint, cast iron pipe 2 in. thick is used.

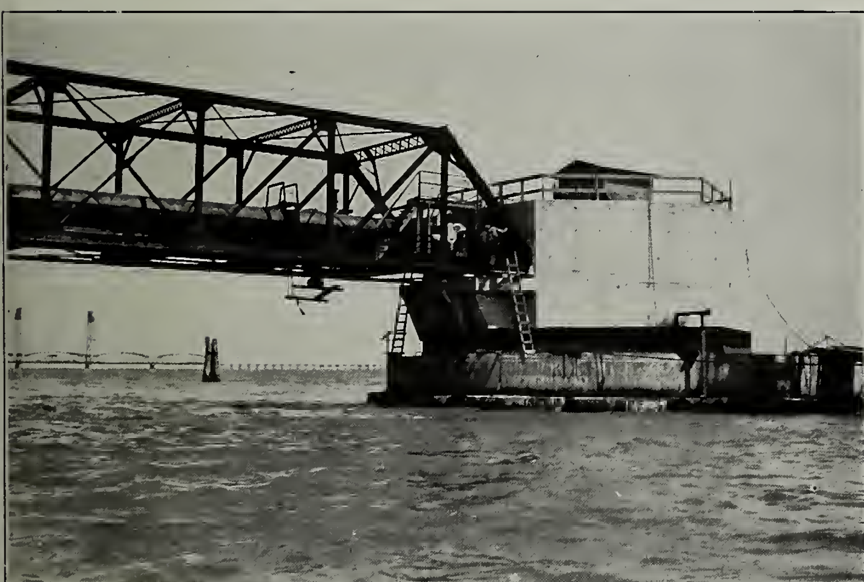
The deep portion of San Francisco Bay at Dumbarton Strait is crossed by 0.6 mi. of this flexible joint pipe laid in a trench excavated in the bottom of the bay at a maximum depth of 70 ft. below water. The westerly end of the submerged pipe enters a concrete caisson in the form of the frustum of an oblique, hexagonal pyramid with external diameter of 81½ ft. at the base and 40 ft. at the top, which rests on 715 piles. This caisson forms the first pier of a bridge of 36 steel spans, each 105 ft. long, all on concrete piers resting on piles, which extends westerly to the San Mateo County shore near Ravenswood Point. The construction of this concrete caisson was exceedingly difficult. Connections are provided in it for three future submerged pipes in addition to the present installed one and it may even be used for the terminus of a future tunnel under Dumbarton Strait. The bridge is designed to carry two pipes, each 6 ft. 4 in. diameter, but at present is occupied by one 5-ft. pipe.



LAYING 42 IN. DIAMETER SUBMARINE PIPE AT DUMBARTON STRAIT



DUMBARTON PIPE BRIDGE



DUMBARTON CAISSON. SUBMARINE PIPE JOINS PIPE ON BRIDGE

A portion of the Bay crossing pipe line, 1.3 mi. in length lying immediately west of the tunnel at Irvington Portal, has not yet been laid, but bids for its construction will be received shortly so that the pipe may be completed in connection with the emergency pipe line that will be described later, before the middle of 1932.

Pulgas Tunnel:

At the westerly end of the pipe line the water flows through Pulgas Tunnel to discharge through an outfall canal into Crystal Springs reservoir. This tunnel is 1¾ mi. long, of horseshoe shape 10 ft. 3 in. in diameter, of the same characteristics as the mountain tunnels, and its inlet is at elev. 290.5. This elevation is set so that the water will discharge by gravity, without pumping, into Crystal Springs reservoir from Moccasin tail-race reservoir when the Crystal Springs dam shall have been ultimately raised to final elevation. The cost of the entire Bay crossing division, including the tunnel, is about $6,000,000.

Plans for the future contemplate the extension of the tunnel route from Pulgas tunnel northerly into San Francisco to discharge into Amazon reservoir at elev. 250 ft. This tunnel extension will require construction of two pipe lines, one across San Mateo Creek and one across San Bruno Valley.

CITY RESERVOIRS

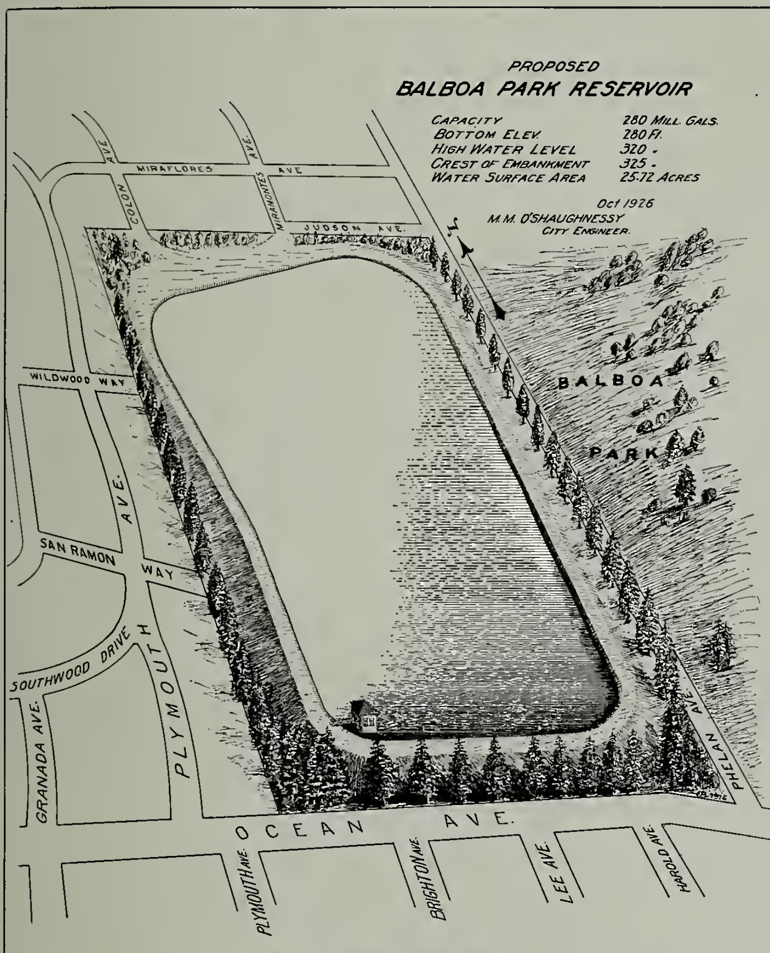
Balboa Park reservoir will occupy at 42-acre site lying north of Ocean Avenue and west of Phelan Avenue. A reservoir of 280 m. g. capacity at elev. 320 ft. may be constructed here. This site, acquired originally by the water company in 1893 for this purpose, is now owned by the City and held for reservoir uses.

Amazon reservoir, the terminal reservoir of the aqueduct, will receive Hetch Hetchy water directly by gravity from Moccasin power house. It will be constructed on a site of 56 acres on Geneva Avenue about ½ mi. east of Mission Street, which already has been acquired by the City. From this elevation approximately one-half of the water consumed in San Francisco may be distributed by gravity. Capacity of the reservoir will be 350 m. g. with water surface at elev. 250 ft.

Glen Park reservoir will be situated in a canyon below Portola Drive and south of Twin Peaks. At the lower end of this valley there is an excellent bed-rock site for a dam 150 ft. high, of the same general type as Priest dam, which will provide a storage of 500 m. g. at elev. 385 ft. Of the 167 acres required at this site 120½ acres have already been acquired by the City. This area acquired includes 82½ acres purchased and 38 acres in streets closed or to be closed.

The construction of these three reservoirs within the City is absolutely necessary to safeguard the water supply in case of a disaster similar to that of April 18, 1906. At that time all of the main aqueducts leading into the city were broken and although the pumping station from Lake Merced began

delivering water into the mains sixteen hours after the earthquake, on the fourth day after the shock the total storage in all of the reservoirs within the City was only 7 m. g., or about 1/20 of their present capacity. The average daily consumption in San Francisco is now 52 m. g. The fire resulting from the April 1906 earthquake caused losses of over $500,000,000 worth of property in an area of 2,381 acres.

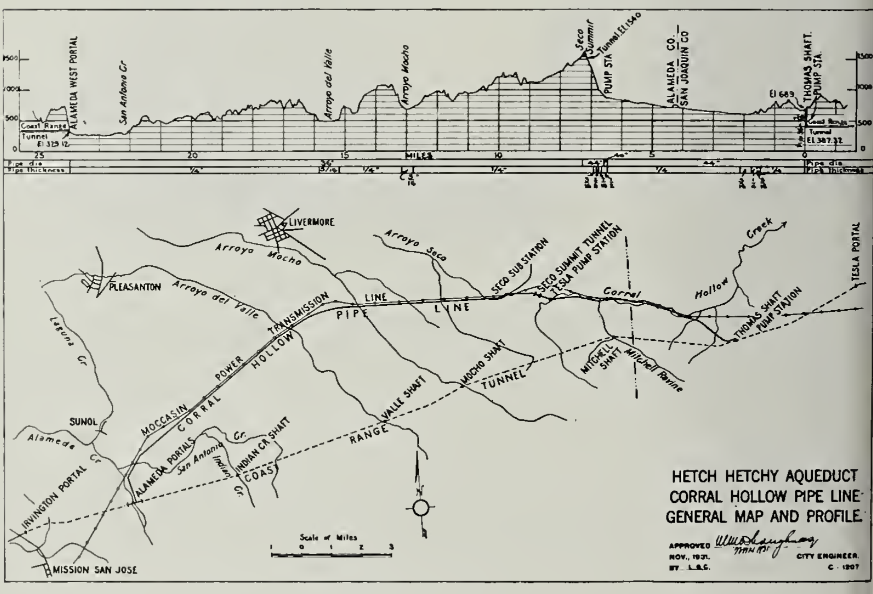


EMERGENCY WATER SUPPLY

As has already been noted, one of the stipulations of the Raker Act requires that the City use the waters "which it now has or may hereafter acquire" before utilizing the Hetch Hetchy water. The sources of the Spring Valley Water Company system now owned by the City have always been estimated by disinterested hydraulic engineers to be capable of producing from 60 to 65 m. g. d. with average rainfall of 22 inches in San Francisco. The present consumption of water from this system averages 52 m. g. d., a figure that increases about 3 per cent annually. It is evident, therefore, that the local system should be ample for the needs of the city until well after 1932. For this reason the time of completion of the Hetch Hetchy system was originally set for 1932.

During the last twelve years California has experienced a number of dry seasons, the last four of which have been especially acute. In consequence, the local reservoirs have been depleted to the lowest storage on record. Early in 1930 it became apparent that additional water must be developed.

The first means of augmenting the supply was the construction of a well system on Forty-fourth Avenue in the Sunset District. This system had been advocated a number of years ago by the City Engineer, but was not adopted by the water company until shortly before the time the City acquired the company's system. The company then began boring wells and the City completed the work. This well system is yielding almost 6 m. g. d.

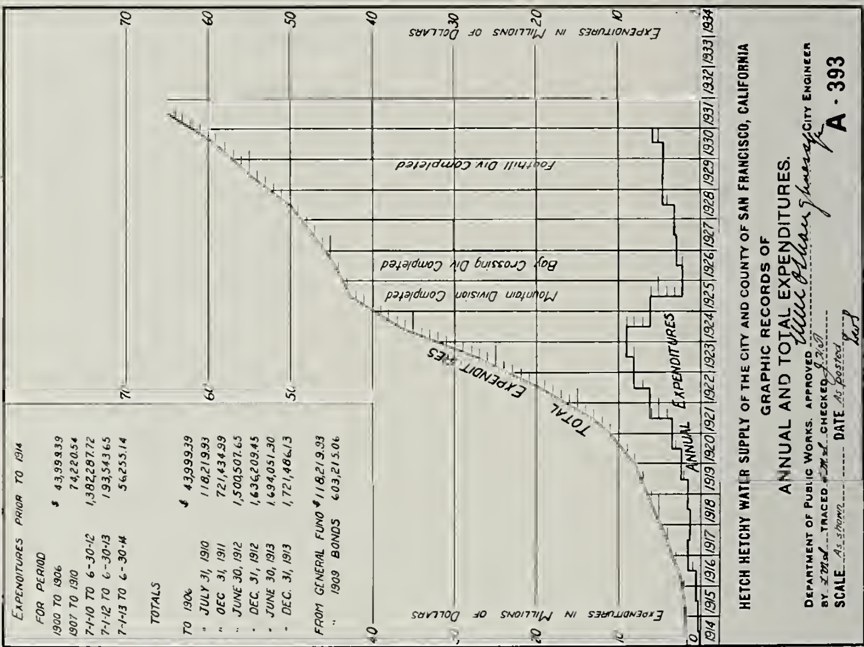


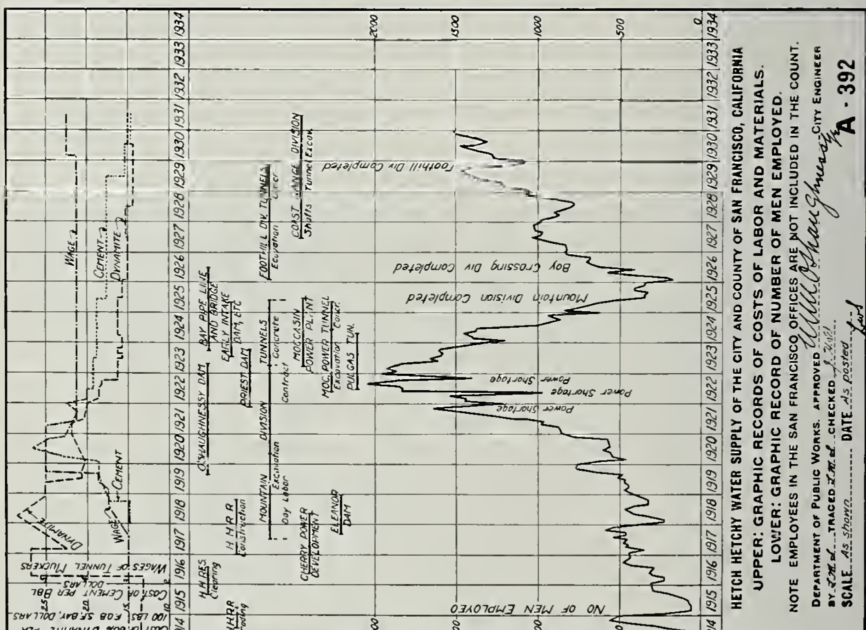
The water encountered in driving the Coast Range tunnel sinks through the gravels to be intercepted by the Water Department's Sunol filter beds. The supply from these tunnels averages about 4 m. g. d.

In October, 1930, it was decided to purchase from East Bay Municipal Utility District 20 m. g. d., which it was estimated would be ample in case the rainfall during the winter season should be normal. To carry the water to the City's aqueducts the Newark-San Lorenzo emergency pipe line, consisting of 12½ mi. of 36 and 44 in. pipe and a pumping station of 20 m. g. d. capacity, was built. The winter's rainfall, instead of being normal, was but 15 in., and it became necessary to double the pumping capacity at San Leandro pump station. At present the City is obtaining about 30 m. g. d. from this source.

If the drought of the last few years should continue into next winter even the present completed emergency supplies might prove inadequate. It has, therefore, been decided to rush additional emergency construction of the Hetch Hetchy aqueduct so as to deliver mountain water from Hetch Hetchy to San Francisco by June, 1932. The construction features necessary to accomplish this are: completion of pipe at Red Mountain Bar in the foothills; construction of the San Joaquin Valley pipe line and of a temporary pipe and pumping system to bypass the uncompleted 7 mi. of Coast Range tunnels, together with a connection from the westerly end of the tunnel to the existing Bay Crossing pipe line.

The emergency pipe line over the Coast Range Mountains will utilize the completed section of tunnel from Tesla Portal, the end of the San Joaquin pipe, to Thomas shaft, a distance of 4½ mi. A pumping station in the tunnel will lift the water 565 ft. to the surface and along Corral Hollow to a point near the old Tesla coal mine. Here a second pumping station will raise the water against a 685-ft. head to a tunnel 7 ft. x 7 ft. and 700 ft. long, which pierces the summit of the ridge at elev. 1,540 ft., whence it will flow by gravity to Alameda west portal to pass through the 3½-mi. completed tunnel to Irvington portal. This line is planned for a delivery of 45 m. g. d., which is considered ample to build up storage in the local reservoirs to a safe figure. The line will consist of approximately 24 mi. of 36 in. and 44 in. diameter pipe. The pumping stations will contain three centrifugal pump units of 15 m. g. d. capacity each, driven by synchronous motors, the power for which will be taken from the main Hetch Hetchy transmission line from Moccasin to Newark via Seco substation near Livermore.


EXPENDITURES PRIOR TO 1914
FOR PERIOD
1900 TO 1906 $ 43,999.39
1907 TO 1910 74,220.54
7-1-10 TO 6-30-12 1,382,287.72
7-1-12 TO 6-30-13 193,543.65
7-1-13 TO 6-30-14 56,255.14
TOTALS
TO 1906 $ 43,999.39
" JULY 31, 1910 118,219.93
" DEC 31, 1911 721,434.99
" JUNE 30, 1912 1,500,507.65
" DEC. 31, 1912 1,636,209.45
" JUNE 30, 1913 1,694,051.30
" DEC. 31, 1913 1,721,486.13
FROM GENERAL FUND $118,219.93
" 1909 BONDS 603,215.06
EXPENDITURES IN MILLIONS OF DOLLARS
TOTAL EXPENDITURES
ANNUAL EXPENDITURES
Mountain Division Completed
Bay Crossing Div Completed
Foothill Div Completed
HETCH HETCHY WATER SUPPLY OF THE CITY AND COUNTY OF SAN FRANCISCO, CALIFORNIA
GRAPHIC RECORDS OF
ANNUAL AND TOTAL EXPENDITURES.
DEPARTMENT OF PUBLIC WORKS. APPROVED
CITY ENGINEER
SCALE As shown DATE As posted
A · 393


COST OF 60% DYNAMITE PER 100 LBS F.O.B. S.F. BAY, DOLLARS
COST OF CEMENT PER BBL DOLLARS
WAGES OF TUNNEL MUCKERS
DYNAMITE
CEMENT
WAGE
NO OF MEN EMPLOYED
Power Shortage
Mountain Division Completed
Bay Crossing Div Completed
Foothill Div Completed
O'SHAUGHNESSY DAM
MOUNTAIN DIVISION
BAY PIPE LINE AND BRIDGE
EARLY INTAKE DAM, ETC
PRIEST DAM
MOCCASIN POWER PLANT
MOC. POWER TUNNEL
PULGAS TUN.
FOOTHILL DIV TUNNELS
COAST RANGE DIVISION
CHERRY POWER DEVELOPMENT
ELEANOR DAM
HETCH HETCHY WATER SUPPLY OF THE CITY AND COUNTY OF SAN FRANCISCO, CALIFORNIA
UPPER: GRAPHIC RECORDS OF COSTS OF LABOR AND MATERIALS.
LOWER: GRAPHIC RECORD OF NUMBER OF MEN EMPLOYED.
NOTE EMPLOYEES IN THE SAN FRANCISCO OFFICES ARE NOT INCLUDED IN THE COUNT.
DEPARTMENT OF PUBLIC WORKS. APPROVED
CITY ENGINEER
SCALE As shown DATE As posted
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FINANCES

The Hetch Hetchy project has been financed from the following bond issues:

$ 600,000—Authorized in 1908 to purchase watershed lands and water rights.

45,000,000—Authorized in 1910 (before the Raker Act), which built the main dams, the mountain tunnels, Moccasin power system, the Bay Crossing pipe line, and Pulgas tunnel.

10,000,000—Authorized in 1924 for foothill tunnel and commencement of shaft sinking in the Coast Range.

24,000,000—Authorized in 1928 for San Joaquin pipe line and completion of Coast Range tunnels.

There still remain unsold $4,000,000 bonds of the 1928 issue. These and the money now on hand are sufficient to complete the San Joaquin pipe line, the proposed emergency pipe line over the Coast Range, the Red Mountain Bar pipe and the 1.3 mi. pipe from Irvington portal to connect with the present Bay Crossing pipe line, so as to bring in 45 m. g. d. of Hetch Hetchy water in 1932, and to carry on the tunnel work until the spring of 1932.

Through resolutions of the Board of Supervisors sanctioned by the City Attorney, the following funds have been diverted from the Coast Range tunnel work fund:

East Bay emergency pipe	$1,096,000
Mather-Hetch Hetchy road	250,000
Corral Hollow pipe line	1,850,000
Total	$3,196,000
Extra equipment and extra costs of Coast Range tunnels are estimated	1,000,000
Total amount necessary to be replaced in Hetch Hetchy Bond Fund to restore it for tunnel completion	$4,196,000

The operation of the Moccasin power system with a revenue approximating $2,000,000 annually with total receipts exceeding $14,000,000 since beginning operation in 1925, the lease of the Bay Crossing Division in 1924 to Spring Valley Water Company and its successor, the San Francisco Water Department, for $250,000 annually with total earnings for nearly six years of more than $1,300,000, and the interest exceeding $3,600,000 earned on account of deposited funds of the Hetch Hetchy project, have done much to lessen the amount of taxes levied in the City of San Francisco for water construction purposes.

The healthy condition of finances is shown in the fact that for the fiscal years 1924-25 to 1930-31, the taxes apportioned to water purposes in San Francisco averaged 19 cents. After applying a credit of one cent for interest earnings on funds of the Hetch Hetchy on account of treasury balances on deposit in banks, which sum was placed directly in the General Fund, this figure is reduced to 18 cents, which compares very favorably with the 28 cents average for the same purpose in the East Bay Municipal Utility District.

The following tabulation shows the approximate amount of taxes collected for water purposes:

	East Bay	Hetch Hetchy	
1924-25	.09	.32	
1925-26	.12	.32	
1926-27	.21	.15	
1927-28	.23	.14	
1928-29	.41	.12	
1929-30	.50	.16	
1930-31	.41	.12	(Estimated)
Mean	.28	Mean .19	

ORGANIZATION

A new charter prescribing the form of government for San Francisco went into effect in 1900. This was a great constructive measure framed to take care of the city's future interests and to correct all deficiencies under the Consolidation Act. It was largely the inspiration of Jas. D. Phelan, then Mayor, who was a highly educated man and a large taxpayer. Mr. Phelan initiated the Hetch Hetchy project.

In his valedictory address upon retring from office in January, 1902, Mr. Phelan made the following statement:

"Under the Charter the Board of Supervisors is a legislative body, having no patronage in its gift except its own clerks . . . the Board of Supervisors is engaged exclusively in passing laws or ordinances for the government of the city . . ."

The progress of the Hetch Hetchy System would have been simplified much if this statement had continued true as time went went on.

Mr. Phelan was succeeded by the notorious Schmitz, whose rule was terminated by indictment by the Grand Jury and the courts, which ejected him from office. His successor, Dr. Edward Robeson Taylor, was subsequently elected to office and the Hetch Hetchy project was revived. P. H. McCarthy, a labor leader, held office from 1910 to 1911.

M. M. O'SHAUGHNESSY
City Engineer

In January, 1912, James Rolph, Jr., became Mayor, to continue in office for 19 years. He drafted the present City Engineer from a profitable private practice as Consulting Engineer to assume the position of City Engineer and Chief Engineer of the Hetch Hetchy project.

A new Charter, which was framed in 1931 and goes into effect January 8, 1932, is designed to remedy all the imperfections of the municipal government. Under its auspices the Hetch Hetchy project will be completed.

Under the present Charter, the Hetch Hetchy development is one of the activities of the Department of Public Works, although matters of general policy are subject to the Board of Supervisors.

The City Engineer is Chief Engineer of the project and the Chief Assistant Engineer has direct charge of the work. Each main division of the work has been in charge of a construction engineer. At the present time construction offices are located at Tracy and Oakdale for the San Joaquin pipe line, and at Livermore for the Coast Range tunnel. Legal matters are handled by the City Attorney. Lands and rights of way are under charge of a right of way agent acting under the City Engineer.

The staff consists of:

M. M. O'Shaughnessy........City Engineer
L. T. McAfee........Chief Assistant Engineer
L. W. Stocker........Assistant Engineer
In charge of design and headquarters office.

R. L. Allin........Hydraulic Engineer on design
P. J. Ost........Electrical Engineer
In charge of power operation and general electrical design.

L. B. Cheminant........Assistant Engineer
Publicity and Reports.

H. W. Kephart........Purchasing Agent
Purchasing, correspondence, etc.

J. J. Phillips........Right-of-Way Agent
Lands and rights of way.

C. L. Cook........Engineering Chemist
Chemical and testing laboratory.

H. B. Chaffee........Photography and blueprinting
C. R. Rankin........Construction Engineer
Coast Range tunnel.

L. A. McAtee........Construction Engineer
San Joaquin pipe line.

M. J. Bartell........Construction Engineer
Corral Hollow emergency pipe line.

Thornton Easler........Assistant Electrical Engineer
Supervising power operation.

Willis O'Brien........Auditor
Accounting and payrolls.

The office personnel in the San Francisco headquarters is under the provisions of civil service, excepting the City Engineer. Employees whose duties are entirely outside of the City of San Francisco are not subject to civil service provisions. At various times during the construction consultants have been engaged to prepare special reports for the City Engineer. Among these are:

Frank G. Baum........Electrical Engineer
Dr. Wm. F. Durand........Mechanical Engineer
Dr. Jas. C. Branner........Geologist
Dr. Bailey Willis........Geologist
John D. Galloway........Civil Engineer
Prof. Chas. D. Marx........Civil Engineer
Prof. Chas. Wing........Civil Engineer

COMPENSATION INSURANCE AND HOSPITAL

All employees on construction are insured in the California State Compensation Insurance Fund. A 15 per cent reduction in premiums paid the State was made when the City undertook operation of its own hospital. A fee of $1 per month is collected from each employee for which he receives medical and first aid treatment for any sickness contracted or injury sustained during the period of his employment by the City, except such as might be a result of vicious or immoral conduct or due to causes antedating his employment by the City. Each applicant for employment on the project is required to pass a physical examination by the City's physician.

A hospital was maintained at Groveland, Tuolumne County, from 1917 to 1930 to accommodate patients from the City's personnel. In 1930 this hospital was removed to Livermore, where it is still maintained.

During construction of O'Shaughnessy Dam the contractor maintained a private hospital at Hetch Hetchy.

During the construction of the foothill tunnels a second hospital, mostly for first aid, was maintained at Hetch Hetchy Junction.

Ambulance service is provided, subject to call day or night, for transportation between the various camps and the hospital. The doctor and staff, consisting at present of eight assistants, are subject to call at all times.

Following is the record of cases treated at Livermore hospital for the period from August 25, 1930, to June 30, 1931, a typical period:

Non-hospital cases		1,580
Hospital cases, City employees	711	
Hospital cases, outside patients	94	
Total hospital cases		805
Total cases treated		2,385
Capital operations		56
Average time in hospital for hospital cases		13 days

CAMPS AND BOARDING HOUSES

The camps maintained by the City are models of neatness and sanitation. The food is of first-class quality, well cooked, attractively served, and is always furnished in generous quantity. This policy was dictated not only by humanitarian considerations, but also from an economic standpoint, as well housed and well fed men will certainly stay longer and work with more energy than poorly fed employees. The labor turnover at the camps is remarkably low. The City consistently has rejected offers of contractors desirous of handling the boarding houses and profiteering on the men's food on a contract or percentage basis.

The men are housed in substantial wooden buildings of board and batten construction, well ventilated and well lighted. These cabins are generally built with a double floor, 2 ft. above ground, to prevent dampness. A porch 6 ft. wide extends across the front. Each cabin is equipped with a wood burning heating stove, for which ample fuel is furnished. Laundry service

and bedding are provided by the City at the nominal cost of 10 cents per day. The cabins are kept clean, the wood supply replenished, and the beds made by camp employees. Separate buildings are equipped with shower baths, lavatories, and washtubs with hot and cold water.

Food supplies are purchased in San Francisco, except such green produce as may be obtained locally. Fresh meat is shipped from San Francisco packing houses in refrigerator cars, and distributed immediately to the camps. At the beginning of construction the rate for board was $1 per day. When prices of foodstuffs and labor rose to such a point that the boarding houses were run at a serious loss, it became necessary to increase this to $1.25 per day, which rate is still in effect.

WATER SUPPLY OF SAN FRANCISCO PENINSULA

The suburban communities in that portion of San Mateo County watershed tributary to San Francisco Bay secure their water from over thirty separate water supply agencies. Much of the supply is derived from wells which tap the underground water supply. These communities have shown remarkable growth in population. This growth has been effective in two ways in diminishing the available storage of water—the increasing population requires more water and the increasing amounts of roads and pavements divert surface waters to sewers and to the Bay, where they do not replenish the underground storage. Consequently, the continuous draft has lowered the

LIVERMORE HOSPITAL

supply of underground water and the well supplies are getting more and more precarious. Steps must be taken immediately by these communities to provide greatly increased supplies for their future needs. Their limited financial resources will prevent their undertaking the introduction of major supplies and it is inevitable that they become customers of the City's combined Hetch Hetchy and Spring Valley system.

At the present time a strong sentiment is growing in these communities for the formation of a water district, or districts, to take water from the City's system and install their own distribution system, and it appears that as time goes on this system will be called upon to furnish water for the whole peninsula, possibly as far south as San Jose, and for the easterly side of the Bay northerly to Niles, or further.

SPRING VALLEY WATER COMPANY'S SYSTEM

The purchase of the system of Spring Valley Water Company has already been noted. This company, since 1858, had built up a system capable, under normal rainfall conditions, of supplying 65 m. g. d. A number of attempts had been made in previous years to purchase the lands and structures by the City. In these campaigns the City Engineer as chief technical adviser for the City made every effort to encourage the acquisition by the City so that the furnishing of water from these local sources might be placed under public control. On May 1, 1928, the citizens by a vote of 82,490 for, and 21,175 against, authorized a $41,000,000 bond issue to purchase the parts of the system used or useful in supplying the City with water.

After prolonged negotiations and discussions, through the cooperation of the Mayor, the Supervisors and the City Attorney, the transaction was finally consummated on May 3, 1930, when bonds were sold through cooperation of the Bank of Italy and operation was taken over by the City and vested in the newly constituted San Francisco Water Department.

Bonds:

The bonds issued, known as "Spring Valley Bonds," are dated July 1, 1928. They bear interest at the rate of 4½ per cent per annum, payable semi-annually and are redeemed serially beginning July 1, 1930, at the rate of $1,000,000 per annum.

Finances:

Report by William Dolge, Auditor, states that the total income for the fiscal year ending June 30, 1931, was		$6,761,527.23
Total expenses, including a depreciation charge of $60,000		4,273,866.52
Leaving a stated net income of		$2,487,660.71
Of this amount there was appropriated for additions to plant	$1,160,760	
Appropriated for bond redemption	1,000,000	2,160,760.00
Leaving, as addition to unappropriated surplus		$ 326,900.71

This is a satisfactory showing of public operation of this great utility.

Main Sources of Supply:

The major items of which the City acquired ownership are:

Over 62,000 acres of reservoir and watershed lands in San Francisco, San Mateo, Santa Clara and Alameda Counties;

Five impounding reservoirs of total capacity 65 billion gal.; the Pleasanton well system, and the Sunol filter beds;

All riparian and other rights necessary to protect the right to divert and use the waters from the seven sources;

Main aqueducts totaling 111 mi., consisting of pipe lines, conduits, and tunnels carrying the water in to San Francisco, and pumping stations on the aqueducts;

All necessary rights of way for aqueducts, roads, power lines, etc.;

A distribution system consisting of 20 reservoirs and tanks of combined capacity of 135 m. g., 750 mi. of pipe, and all necessary pumping stations;

Over 100,000 consumers.

The property consists of 62,612 acres of land in four counties:

	Acres
San Francisco	968
San Mateo	23,775
Alameda	24,267
Santa Clara	13,602
Total	62,612

The seven sources comprise four impounding reservoirs, one reservoir (Lake Merced in San Francisco) from which percolating waters are pumped, the Pleasanton well system at the lower end of Livermore Valley, and the Sunol gravel beds from which percolating water is drawn. The greater part of the water produced is naturally filtered, while that from the three impounding reservoirs in San Mateo County comes from an area publicly owned on which trespassing is prohibited. Waters from all the sources are chlorinated.

Water is distributed in San Francisco from sea level up to 800 ft. elev. by means of a series of pressure zones of varying elevations.

Operation of the San Francisco Water Department is under N. A. Eckart, General Manager, who was formerly Chief Assistant City Engineer.

HETCH HETCHY AND LAKE ELEANOR RESERVOIRS

	Hetch Hetchy Reservoir		Lake Eleanor	
	Initial	Ultimate	Present	Ultimate
Area of watershed, sq. mi.	459	459	79	193†
Capacity of reservoir, m. g.	67,000	113,500	9,000‡	71,000‡
Acre ft.	206,000	348,500	28,000	218,000
Water surface area, acres	1,600	1,940	945	1,475
Sq. mi.	2.5	3	1.5	2.3
Elev. of roadway on dam, ft.	3,726.5	3,812	4,661	4,825
Elev. of spillway crest, ft.	3,719.75	3,800	4,657	4,810
Length of reservoir, mi.	7.5	8	3.1	3.2
Width of reservoir, maximum mi.	0.65	0.7	1.0	1.1
Width of reservoir, average, mi.	0.33	0.38	0.5	0.7
Depth of reservoir from spillway crest: maximum, ft.	220	300	57‡	210‡
Dam:				
Type of dam	Concrete, gravity section arched in plan		Reinforced concrete buttressed arch	Rock fill with concrete facing
Total length on crest, ft.	605	900	1,260	2,000
Height of crest above stream level, ft.	226.5	312	60	225
Depth from stream level to bedrock, maximum, ft.	118	118	10	10
Total height of dam, above bedrock, ft.	344.5	430	70	235
Width at top, ft.	15	25	------	25
Width at base, maximum, ft.	298	298	------	700
Volume of masonry, cu. yd.	398,516	625,000	11,640	------
Type of spillway	Siphon	Channel around end of dam	Overflow	Channel around end of dam

†Includes Cherry watershed above proposed diversion.
‡Lake Eleanor depths and capacities do not include the portion of original lake not available for draft.

PRIEST AND MOCCASIN RESERVOIRS

	Priest Regulating Reservoir	Moccasin Regulating Reservoir
Capacity, millions of gal.	766	114†
Acre ft.	2,350	350†
Water surface area, acres	52	26†
Dam:		
Type	Earth and rock fill	Earth and rock fill
Crest elev.	2,245	927
Crest length	1,160	855
Crest height above streambed	147.5	50
Crest width	20	27.5
Base width, maximum	660	330
Spillway, type	Open channel	Open channel
Capacity	800 sec. ft.	9,000 sec. ft.
Elev. of lip	2,240	911†
Fill vol., rock toes from tunnel	104,476 cu. yd.	
Hydraulic fill	247,656 cu. yd.	
Dry earth and rock	350,597 cu. yd.	143,341 cu. yd.
Riprap face	14,554 cu. yd.	
Total	717,283 cu. yd.	
Core wall, type	Flexible concrete	Monolithic concrete
Volume, cu. yd.	17,043	3,592
Height, ft.	160	73
Thickness	2′ and 6′	14″ to 18″

†Installation of radial gates in spillway will increase these figures.

RESERVOIRS FOR FUTURE DEVELOPMENT

	Poopenaut Valley	Cherry Valley	Lake Vernon	Huckleberry Lake	Emigrant Lake
Area of watershed, sq. mi.	473†	114*	40‡	17†	11†
Capacity of reservoir:					
Millions of gal.	10,000	18,500	16,600	17,000	4,600
Acre ft.	31,000	57,000	51,000	52,200	14,250
Water surface area:					
Acres	383	1,150	640	800	320
Sq. mi.	0.6	1.8	1.0	1.25	0.5
Elev. of spillway crest, ft.	3,468.5	4,550	6,630	7,700	8,700
Length of reservoir, mi.	2.3	3.4	2	4	2
Width of reservoir:					
Maximum, mi.	0.55	0.8	0.7	0.5	0.3
Average, mi.	0.45	0.53	0.5	0.3	0.25
Depth of reservoir:					
Maximum, ft.	160	150	105	100	60
Average, ft.	81	50	80	65	45
Type of dam	Concrete gravity section	Rock fill	Rock fill or Eleanor type	Rock fill	Rock fill
Length of dam, ft.	370	1,060	2,000	520	420

†Includes Hetch Hetchy watershed.
*Cherry Valley watershed includes watersheds of Huckleberry and Emigrant Lakes.
‡Included in Hetch Hetchy watershed.

POWER DEVELOPMENT POSSIBILITIES

Location of plant	Early Intake	Moccasin		Red Mountain Bar	Early Intake	North Mountain
Source of water supply	Cherry River	Hetch Hetchy and Lake Eleanor		Hetch Hetchy and Lake Eleanor	Hetch Hetchy	Lake Eleanor
Aqueduct, type	Pipe, canal and tunnel	Pressure tunnel		Pressure tunnel	Pressure tunnel	Canal and tunnel
Aqueduct length, mi. (not incl. pressure pipes)	3.3	19.8		5.2	11	7.6
Aqueduct cap. sec. ft.	200	700		620	620	200
Forebay, type	Large pipe	Reservoir			None	None
Forebay capacity:						
Gallons	250,000	800,000,000		205,000,000		
Acre ft.	0.7	2,350		630		
Pressure Pipes:		Present	Proposed			
Length, ft.	530	5,350	5,580	950	2,500	5,700
Number of pipes	1	2	3	1		
Diameter of pipes	3′ 6″	104″-54″	104″-54″	114″-96″		
Gross drop, ft.	345	1,316	1,316	330	1,100	2,000
Power plant:						
24-hour average capacity						
kv-a	3,000	60,000	60,000	15,000	42,000	24,000
h. p.	4,000	75,000	75,000	20,000	56,000	32,000
Number of generators	3	4	6	2		
Capacity each, kv-a	1,100	20,000	17,500	10,000		
Total installed capacity						
kv-a	3,300	80,000	120,000	20,000		
h. p.	4,400	100,000	150,000	30,000		

NOTE: Development of Huckleberry and Emigrant Lakes as reservoirs will make available additional power, the amount of which has not yet been determined.

CHRONOLOGY, HETCH HETCHY WATER SUPPLY

Jan. 8, 1900	New Charter in effect.
Mar. 26, 1900	Solicitation of offers of sale of water supplies to City.
July 29, 1901	Appropriations made on water at Hetch Hetchy and Lake Eleanor by Jas. D. Phelan.
Aug. 12, 1901	City Engineer recommends Tuolumne River as source of water for San Francisco.
Oct. 16, 1901	Filings of same at Stockton Land Office.
Jan. 20, 1903	Phelan's applications denied by Secretary of the Interior Hitchcock.
Feb., 1903	Petition for rehearing, by Franklin K. Lane, City Attorney.
Feb. 20, 1903	Filings assigned to City.
Dec. 22, 1903	Application again denied by Secretary of the Interior.
May 11, 1908	Original applications approved by Secretary of the Interior Garfield.
Nov. 12, 1908	Special election authorized construction of Tuolumne System and issue of $600,000 of bonds to buy lands, etc.
Jan. 14, 1910	Bond election, $45,000,000 bonds authorized by vote of 20 to 1.
Feb. 25, 1910	Order to show cause why Hetch Hetchy should not be eliminated: Secretary of the Interior Ballinger.
May 12, 1910	Secretary of the Interior requested Secretary of War to appoint Board of Army Engineers to act as Advisory Board.
May 18, 1910	Board appointed.
July, 1912	"Freeman Plan" of Hetch Hetchy development published and submitted to Army Board.
Sept. 1, 1912	M. M. O'Shaughnessy appointed City Engineer.
Nov. 25 to 30, 1912	Hearings before Secretary of the Interior Fisher, attended by Mayor, City Engineer, City Attorney and consulting engineers.
Feb. 9, 1913	Army Board report upholds selection of Tuolumne River as $20,000,000 cheaper than any other system and having greatest power possibilities.
March 3, 1913	Conference: City Engineer with Secretary Fisher.
June 25 to July 7, 1913	Hearings by committee on the Public Lands, House of Representatives.
Dec. 19, 1913	Hetch Hetchy Grant, or "Raker Act," signed by President Wilson.
July, 1914	Report of Consulting Engineers, W. F. Durand, J. D. Galloway and F. G. Baum received.
July 8, 1914	Bids received by Board of Public Works for Contract No. 1, for constructing road from Hog Ranch (now Mather), to Hetch Hetchy.
July 21, 1915	Began manufacture of lumber at Canyon Ranch.
Sept., 1915	Began construction of camp buildings at Hetch Hetchy, clearing of Hetch Hetchy Reservoir site, and construction of Diversion Tunnel.
Nov. 24, 1915	Bids received for construction of Hetch Hetchy Railroad.
Aug. 9, 1916	Bids received for "Drifting Tunnels, Lower Cherry Aqueduct," already begun by day labor.

CHRONOLOGY—*Continued*

Oct., 1917	Hetch Hetchy Railroad operation began.
May 6, 1918	Lower Cherry Power House began operation.
Aug. 1, 1919	Contract awarded for construction of Hetch Hetchy Dam.
May 3, 1920	Contract awarded for construction of Aqueduct Tunnels in Mountain Division, this work having been carried on so far by day labor.
Fall, 1921	Work began on Priest Dam.
Fall, 1921	Work began on Moccasin Power House.
June 23, 1922	Contract awarded for construction of Pulgas Tunnel.
May 18, 1923	Contract awarded for construction of Bay Crossing Pipe Line.
July 7, 1923	O'Shaughnessy Dam dedicated.
Oct. 7, 1924	Special Election $10,000,000 bonds authorized to construct Foothill Tunnels and begin Coast Range Tunnels, vote 20 to 1.
Aug. 14, 1925	Delivery of power began from Moccasin Power Plant.
Dec. 14, 1925	Budget of expenditures for Foothill and Coast Range tunnels submitted to Supervisors.
Feb. 8, 1926	Budget for **Foothill Tunnels only,** approved by Supervisors. Construction of 16-mi. tunnel began immediately.
May 21, 1926	Bay Crossing aqueduct began full operation.
Sept. 20, 1926	Contracts awarded for driving portion of Foothill Tunnels. Remainder done by day labor.
Oct. 4, 1926	Budget for Coast Range Tunnels again submitted to Supervisors.
Jan. 15, 1927	Report of Dr. W. F. Durand substantiated City Engineer's policy of driving Coast Range Tunnels.
Mar. 5, 1927	Budget for Coast Range Tunnels approved by Supervisors.
April, 1927	Coast Range Tunnel construction began at Mocho shaft. Sinking began in May.
May 1, 1928	Bond election, $24,000,000 bonds authorized by vote of 7 to 1, to construct Coast Range Tunnel and San Joaquin Pipe.
May 1, 1928	Bond election, $41,000,000 bonds authorized by vote of 4 to 1, to purchase Spring Valley Water Company system.
May 25, 1928	Budget submitted to Supervisors for construction of Coast Range Tunnel and San Joaquin Pipe. Approved as to tunnel.
Sept. 6, 1928	Tunnel driving began at Tesla Portal of Coast Range Tunnel.
Dec. 6, 1928	Foothill Tunnel driving completed.
March 3, 1930	San Francisco Water Department takes over operation of system bought from Spring Valley Water Company.
Aug. 26, 1930	Bond election, $68,115,000 bonds for acquisition of power distribution system fail to carry.
March 4, 1931	Tunnel 4.4 mi. long "holed through" from Tesla Portal to Thomas Shaft in Coast Range.
May 22, 1931	Contract awarded for construction of San Joaquin Pipe Line.
Aug. 11, 1931	Tunnel 3.4 mi. long "holed through" from Alameda Creek to Irvington Portal.
Oct. 28, 1931	Contract awarded for construction of Red Mountain Bar Siphon.
Nov. 6, 1931	Contract awarded for construction of Corral Hollow Emergency Pipe Line.

ELEVATIONS OF VARIOUS POINTS ON HETCH HETCHY PROJECT

Feet	Point
13,090	Summit of Mt. Lyell, highest point on watershed.
4,825	Future Lake Eleanor Dam crest.
4,810	Future Lake Eleanor Dam high water.
4,661	Lake Eleanor Dam, present crest.
4,590	Lake Eleanor Dam, creek bed.
3,812	Future O'Shaughnessy Dam crest.
3,726.5	Present O'Shaughnessy Dam crest.
3,500	O'Shaughnessy Dam river bed.
3,382	O'Shaughnessy Dam lowest point of foundation.
2,356	Early Intake Diversion Dam crest.
2,346	Early Intake Diversion Dam, normal water surface.
2,326	Early Intake Diversion Dam, floor of mountain tunnel.
2,345	Priest dam, crest.
2,240	Priest regulating reservoir high water.
2,169	Priest portal of mountain tunnel, floor.
2,145	Moccasin power tunnel floor of inlet.
2,120	Priest Dam, auxiliary drainage tunne', floor.
2,272	Moccasin surge shaft top.
2,112	Moccasin surge shaft floor.
924	Moccasin power house nozzles.
927	Moccasin Dam crest.
920	Moccasin Reservoir normal water surface.
881	Foothill Tunnel, floor at Moccasin Reservoir.
747	Foothill Tunnel, floor at Oakdale portal (at easterly edge of San Joaquin Valley).
—1.4	San Joaquin River crossing, bottom of pipe.
399	Coast Range Tunnel floor at Tesla portal (at westerly edge of San Joaquin Valley).
316.4	Coast Range Tunnel floor at Irvington portal.
—68.5	Dumbarton Strait crossing, bottom of pipe.
290.5	Pulgas Tunnel, floor at Redwood portal.
250	Amazon Reservoir, San Francisco, water surface proposed.
320	Balboa Park Reservoir, San Francisco, water surface proposed.
385	Glen Park Reservoir, San Francisco, water surface proposed.